HOW CHILDREN DISCOVER KNOWLEDGE

NARENDERA VAIDYA

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High examination marks are necessary but not sufficient indicators of top scientific acumen. Contrary to popular belief, science is not a hard fact gathering activity. Instead, it is a great human enterprise in which the futuristic man of science is compelled to think, imagine, speculate and consult Book of Nature when he begins to investigate and disclose in bits the mysteries of nature.

Other Books by the Author

1. The Outcomes of Basic Education (In Collaboration, 1961).
2. Planning for Science Teaching (In Collaboration, 1968).
3. Survey of Physics Teaching in Rajasthan (In Collaboration, 1968).
4. Problem Solving in Science (1968).
5. Strategies in Science Education (In Collaboration, 1970).
6. The Recent Trends in Technical Instruction (1971).
7. Some Aspects of Piaget's Work and Science Teaching (1971).
8. The Impact Science Teaching (1971).
9. Reshaping Our School Science Education (In press).
10. The Growth of Logical Thinking (The Cognitive Processes during Adolescence) (In press).
11. The Modification of Teacher Behaviour Using Interaction Analysis and Microteaching (Under preparation).
12. The Growth of Scientific Concepts (The cognitive processes during childhood) (Under preparation).

    Three Collaborative NCERT and Regional College Projects (In progress).

13. Individually Accelerated Science Teacher Education Project.
14. The Survey of Science Laboratories in M.P.
15. My Fealings Towards Science.

HOW CHILDREN DISCOVER KNOWLEDGE

THEORETICAL AND PRACTICAL FOUNDATIONS
OF STUDENT INVESTIGATIONS IN SCIENCE

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FOREWORD

It is well known that up to about the middle of the 16th century scientific developments in India were comparable to those anywhere else in the world, but that subsequently a number of social, economic and political factors led to lag in the development of Indian Science. Over the centuries the adverse circumstances faced by Indian Industry, agriculture and cultural life in general contributed to the backwardness of Indian Science. In the advanced countries of the world, their progress was partly due to the development of science, which itself was making a contribution to the development of means of production and of cultural life. However, even in some of the advanced countries scientific thinking, and a scientific culture had not permeated the life of the people very deeply. In particular, a deep consideration of science education was a neglected subject until recently.

Since independence we in India have seen a great expansion in the field of scientific education and research. The number of schools, colleges and universities which have developed first-rate facilities for education in science is very considerable. Scientific research has been expanding at such a rate that some people have estimated that it is doubling in every four or five years. The National Council of Educational Research and Training has played a very important role in expanding and raising the standard of education in science particularly by providing good textbooks and by developing a number of kits. New ideas of enriching science education through work experience, field work and discovery approach are a recent phenomenon. Nevertheless, one is constrained to say that the qualitative change in science education which could have been expected has not yet come about, although we are moving in that direction.

One of the serious defects of science "teaching" is that it is almost totally information-based. This makes scientific education at the lower levels a very drab and matter-of-fact business which often bores students. At the higher levels it runs through the risk of becoming out of date before the student reaches maturity and takes up any scientific work on his own. The learning becomes highly limited. Science which is an admirable synthesis of learning and production activity becomes a stereotype. The characteristic features of science of being open ended, of welcoming change, and of being based on reason, are given scant attention. Science education instead of becoming a liberating and intellectually stimulating experience becomes another kind of cut-and-dried dogma.

The present book of Mr. Vaidya on "How Children Discover Knowledge" does not fill the gap since the gap is much too wide but it attempts to throw a bridge across it. Mr. Vaidya is a teacher of very long and varied experience and in the chapters of his book he has in his own inimitable manner described the nature of scientific enterprise, the nature of thinking and problem solving and of science as an adventure. I am sure that the teachers of science can learn a great deal from this book. I hope the book will play a part in transforming science education to its cherished image in our country.

RAIS AHMED
Director
National Council of Educational
Research & Training,
New Delhi

November, 1974

PREFACE

Why this book ? First, the scientific education of our young boys and girls, at a critical stage of their mental development, hardly goes beyond the transferring of liquids from one container to another in chemical experiments, making measurements as directed, and solving model problems. Research and innovation are not built into the system. Secondly, like any other teacher, the science teacher talks too much in the classroom. He lectures dogmatically as well as authoritatively on prescribed topics of science which are remotely related to the behavioural objectives of science education. Thirdly, because of old traditions in his local set-up, he sees no relevance in stimulating and cultivating scientific and technical talent. All this results in a poor crop of swift, sceptical, curious and young vibrating minds to run the race in science. Fourthly, the school appears to be a place where children make little use of their talents and tools because the methods of teaching in vogue are not only mechanical in character but also devoid of constructive imagination. Fifthly, teachers from their unexamined, day-to-day classroom teaching form firm opinions about their wards which prove too difficult to eradicate later on. Sixthly, science teaching at all levels has changed radically, in both content and form, in the wake of the recent scientific revolution. Seventhly, but indirectly, the texture of the consequent problems for the science teachers is changing very fast—'not the reblooming of a perennial' but of obtaining a 'new mutant' surmounting individual circumstances (J.J. Schwab). Lastly, a book was needed which treated exhaustively the theoretical and practical foundations of student investigations in science.

So it is addressed to the individual science teachers and their students, for carrying on securely the entire process of scientific inquiry, accomplishing in the process, the high standards of project reports required in the Science Talent Examination conducted by the NCERT every year against the back drop of Hypotheses Setting and Testing Approach Philosophy.

Science is a branch of human knowledge which not only encourages but also flourishes on rebellion. The best tribute that a disciple could think of paying to his great master is by contradicting his work. Naturally more the controversy, the more revolutionary ideas. Scientific knowledge would be generated with immediate or near immediate impact on other branches of human knowledge including personal and social affairs. "What is Science ?", therefore, receives different answers from different categories of people. A few borrowings from literature really add to the confusion, because these are taught, learned and quoted emotively out of context. In the enthusiasm of teaching new concepts and skills of the recent curricular programmes, it is very frequently forgotten that 'Science, like life, feeds on its own decay' (William James). If sought, points of contact may be discovered between past knowledge and the present knowledge. In 1638, Galileo hypothesized that a water column, like a long rope, broke down under its own excessive weight when a water pump failed to raise it beyond a certain height. Two years later, after the death of his master (Galileo), Torricelli hypothesized and confirmed the existence of air pressure. Prof. Pettenkoffer of Munich swallowed in full public view a whole phial of cholera germs without harm to himself, for he believed firmly in their impotence. He believed in will power or the disposition of the individual. Result : the concept of immunity was born later on. Dr. Paul Ehrlick made 605 unsuccessful efforts before he could develop successfully Salvarsan for the treatment of syphilis. He named it the 606th formula. Howard Rogers studied unsuccessfully about five thousand chemical compounds before he invented a new chemical molecule for obtaining instant pictures. Despite confirming evidence, nobody took seriously the chance relationship that the 'gestation period measured in days of animals ranging from rabbits to cows was a multiple of 22/7'. Father Spllanzani won truth from nature by 'dazzling experiments, close observation and insane patience ; and obtained money and advanced by work, cunning, plots and falsehoods'. 'He received protection from religious persecution by becoming a priest.' It should not be forgotten that scientific experimentation does not invariably yield clear-cut solutions. Scientific evidence, even when collected objectively, does not immediately become acceptable. So, failure in science is not a rare event. What is science then? The literature on history of science answers the question as follows:

Science is a great human enterprise, not only endless and faceless but also stable and fluid. It is less complicated than an erratic lady who cannot correlate her varied behaviours. It is self-growing, self-accelerating and self-correcting which originated in the immense curiosity of man since times immemorial. It attempts to provide an objective body of knowledge, through objective as well as subjective procedures, which is as objective as the prevailing conditions make it, that is, do not challenge it. In every generation, it operates in a certain frame of reference which yields to another imperceptibly and gradually or sometimes even violently in the light of new evidence.

It thus wheels on dogmatism, dynamism and discovery at the same time. Open mindedness, arousal and maintenance of curiosity, questioning the basis of all things (including assumptions), collection of data, demand for verification and proof, respect for mathematical arguments and logical proofs, including statistical reasoning, suspended judgement, acceptance of warranted conclusions and willingness to change one's opinion in the light of new evidence are some of the prominent ferments which characterize the scientific enterprise. Interestingly enough, it is an international activity, least confined to national frontiers. Incidentally, accidentally and intentionally (through research and development followed by the commercial exploitation of scientific discoveries), it strengthens national economies, creates new resources, accelerates vast employment and attempts to build global outlook on problems which affect man and his life.

One cannot fail to see that the era of making positive and assertive statements in science is now gone. With this is also gone the age of putting stereotyped questions and obtaining fixed answers. It does not need any emphasizing that the scientific education of our young boys and girls towards the latter half of the twentieth century and even beyond it demands that ferments like discovery approach, mastery of research operations in their varied aspects, teaching for problem solving, and the development and improvement of thinking and self-education need to be cultured on a large scale so that our pupils may live successfully in a world highly loaded with science and technology. Emphasis on the methods and processes of science should desist teachers from following the path of least resistance, that is, taking short cuts. There will be thus less interference with the vision of a more fundamental objective of teaching science which is to develop among the vast body of pupils the 'patient, systematic observation of facts, the design of experiments to isolate what is to be studied, the formulation of hypotheses for subsequent verification, the practical and theoretical integrity of the process of verification, the willingness to abandon any hypotheses not substantiated experimentally, and the consistent maintenance of an attitude of detached objectivity in their day-to-day thinking' (S. Nisbet). This is only possible if science students are exposed to fundamental scientific phenomena in their early years. They will then learn not only how to tackle a given problem efficiently but also what it means to tackle it experimentally. In the absence of this exposure, a situation like paralysis develops which inflicts everybody in the profession to a varying degree, in which each one fails to pull himself up by his own hair and to turn himself inside out by self-criticism developing in the process, insensitivity to a dissatisfying state of affairs. Consequently, one's outlook becomes not only polarised but also pygmean. Ingenuity, initiative, innovation, novelty, persistence, self-confidence and emotional stability in the face of physical and professional difficulties become the first casualities of the profession. In these circumstances, it is, therefore, quite safe to follow the beaten track. Added expenditure does not define the problem and our intelligent approach to solving problems need not necessarily be pyrrhic. And this book is about Not to Follow the Beaten Tracks and the Pyrrhic Approaches.

What are the purposes of this book? In the light of what has been said, it aims at achieving the following objectives.

1. It deals exhaustively, both theoretically and practically, with the investigative aspects of science.
2. It familiarizes its readers, both young and old, with the nature of scientific enterprise.
3. It emphasizes that science should be taught as well as learnt as a tool subject.

4. It clearly illustrates the role of scientific methods in the acquisition of past as well as current knowledge at the school level.
5. It is generously suggestive rather than prescriptive in assisting students to think and work hard on a given problem in a variety of ways.
6. It indirectly creates abundant resources for advanced instruction and experimentation; and directly strengthens laboratory work and classroom teaching.
7. Lastly, it is a source book for several project ideas for both science students and their teachers heading for partnership in the pursuit of truth.

The organization of this book is very simple. It contains eight chapters in all. The first chapter is elementary and introduces the readers to the investigative aspects of science. The second and third chapters deal exhaustively with the nature of scientific enterprise, and thinking and problem-solving. The fourth chapter on Science As Past Adventure discusses some major scientific episodes which reflect, in the process, the Real Variable Natural Spirit of Science. The fifth chapter discusses Exposure to Fundamental Scientific Phenomena on the cheap. The sixth and seventh chapters report projects and project ideas, essays and improvisations. The last chapter discusses in brief a few frontiers like Stress on Productive Thinking, The Science Youth Project and the Reporting and Judging of Projects. The chapterwise references consulted have been given at the end of the book. Additional references have also been given.

I would like to take the opportunity of thanking the librarians of the Institute of Education, London; The Senate House, London; the Institute of Education, Birmingham; the National Institute of Education, NCERT, New Delhi; the Central Institute of Education, Delhi; Punjab University, Chandigarh; Technical Teachers Training Institute, Chandigarh; and the Regional College of Education, Ajmer. As regards individuals, I am deeply indebted to Principal J. K. Shukla, Principal P. D. Sharma, Principal R. C. Das, Principal G.B. Kanoongo, Dr. M.C. Pant, Prof. A.N. Bose, Prof. Irwin Slesnick and Prof.W.J.Jacobson for clarifying some of my ideas. I am also very much obliged to my colleagues, particularly Shri G.Guru, Shri Piyush Swami, Shri K.C. Goyal and Shri B.S.Singh for their contributions suitably acknowledged in this book. Parts of the manuscript were also read by Shri S.B. Singh, Shri M.K. Gupta, Shri S.C. Jain, Shri I.D. Misra and Miss S.K. Ram. Two projecteers of the Individually Accelerated Science Teacher Education Project: Miss Manorma and Miss Gargi also gave some comments. All these suggestions have given me added confidence in presenting a personal point of view in investigative science, characterized by principles of inquiry, always remaining under constant fire, questioning the plan rather than its details (J.J. Schwab).

Let me now bring this preface to a close. We science teachers in our highly exciting times should also frequently address ourselves to build an Indian Tradition of Science Teaching. For this, no advice is given and no suggestions are made because here, each one of us, whether teacher or student, or scholar, or scientist, must individually do one's own home work, rely more and more on one's own thinking, reach one's own conclusion, or decision, however wrong it might turn out to be in the end rather than depend upon solved examples. Thus, generally speaking, we should not remain satisfied with one solution alone. More alternative solutions should be sought, tentative stabs examined and then investigated to yield fruitful solution or solutions. Each one of us then will be rectifying not only his thinking gradually through self-exploration, observation, experimentation etc. but also growing in self-confidence, persistence and emotional stability in the face of several difficulties, physical, intellectual and emotional. Discovering scientific knowledge in the scientific way (or ways) is the muddle headed attempt and approach to arrive at the immediate goal by carrying on the whole process of scientific inquiry, in its widest possible sense. How Children Discover Knowledge, therefore, tries hard to bridge the gap between the school and the research laboratory against the backdrop of Recent Scientific Knowledge which unsettles us day in, day out in the latter half of the twentieth century.

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NARENDERA VAIDYA

CONTENTS

Foreword v—vi

Preface vii—xii

1. INVESTIGATIVE SCIENCE 1—19

Introduction, Formulated Definition of Science, Illustrations from the History of Science, Illustrations from Classroom Experiences, Focus on Investigative Projects, Functions of Investigative Projects, Features of Investigative Projects

2. THE NATURE OF SCIENTIFIC ENTERPRISE 20—54

Section A—Impact of Science and Technology, Role of Science Education, Functions of Science Education, Assumptions Underlying Science Education Programmes. *Section B*—Outcomes of Science Eduction, What is Science? Definitions of Science, Critical Appraisal, Attempting a Definition of Science, Limitations of Science, Objectives of Science Education, Scientific Appreciations, Concluding Statement

3. THE NATURE OF THINKING AND PROBLEM-SOLVING 55—71

Introduction, Thinking and Problem-Solving, Thinking, Productive Thinking, Problem-Solving, Logical Steps in Problem-Solving, Formulation and Testing of Hypotheses, Scientific Methods, Steps in Scientific Method

4. SCIENCE AS PAST ADVENTURE 72—145

Introduction, Illustrations from the History of Science: The Concept of Electron, Christopher

Columbus on a Voyage of Discovery, The Bending of a Seedling, A Mysterious Nervous Disease, The Discoverer of Some Chemical Elements, The Work of Ronald Ross, Our Universe and the Shape of Earth, From Jungle to Zoo (The Periodic Table), Our Foods, The Story of Vitamins, The Origin of Life, The Emergence of Electron, The Work of Humphry Davy, George Westinghouse, Measuring the Velocity of Light, The Use of History of Science Cases, Concluding Statement

5. EXPOSURE TO FUNDAMENTAL SCIENTIFIC PHENOMENA 146—165

Introduction, Functions of Investigative Projects, Posing the Problem at Depth, Investigatory Projects in Zoology, Further Illustrations of an Investigative Project, Other Examples : Aging and Life Span, Lubricants, Population Studies, Soft Drinks and Tooth Decay, Concluding Statement

6. THE VARIABLE ILLUSTRATION OF SOME SPECIMEN PROJECTS 166—223

Introduction, Analysis of Projects, Evaluation of Projects, Procedure for Studying these Projects, Some Illustrated Specimen Projects : *A*—Physics, *B*—Chemistry, *C*—Biology

7. THUMB-NAIL (INVESTIGATIVE QUESTIONS AND PROJECTS IDEAS) 224—272

Section A—Introduction, Investigative Questions, Method of Procedure, Classification of Problems, Questions Rejected, General Questions, Questions which are in Fact No Questions, Question-Answer

Variety, Advisory Type, Information Type, Miscellaneous Type, Our Living World, General Problems, Experimental Problems, Specific Problems, Concluding Statement. *Section B*—Introduction, Long Essays, Point Investigations and Improvisations. *Section C*—Introduction, Project Ideas in Physics, Chemistry and Biology, Concluding Statement

8. THE OTHER FRONTIERS 273—298

Introduction, Stress on Productive Thinking, Science Youth Project, Science Clubs, Science Exhibition, Reporting and Judging of Projects, Concluding Statement

References 299—310

Index 311—315

1. Investigative Science

The story is told in the University of Paris that the philosophers there once disputed among themselves as to the number of teeth in a horse's mouth. They argued that the number could not be a multiple of three, for that would imply disrespect to the Trinity; nor could it be a multiple of seven, for the God created the world in six days and rested on the seventh. Neither the authority of Aristotle nor the ingenuity of the learned doctors could resolve the problem, but it was finally settled by a vulgar young who opened the mouth of a horse and counted the teeth.

—Eric Ashby

I have been unable to see anything in the constitution of your society to prevent a student from bestowing the most steadfast devotion on pure science. If great scientific results are not achieved in America, it is not to the small agitations of society that I should be disposed to ascribe the defect, but to the fact that the men among you who possess the endowment necessary for a profound scientific inquiry are laden with the duties of administration, of tuition so heavy as to be utterly incompatible with the continuous and tranquil meditation which original investigation demands.

... You have scientific genius amongst you. Take all unnecessary impediments out of its way. Keep your eye upon the originator of knowledge. Give him the freedom necessary for his researches, not demanding from him so-called practical results—above all things avoiding the question which ignorance so often addresses to genius, what is the use of your work?

—John Tyndall

Science teachers can surely find many growing points for the development of a large number of scientific and also mathematical concepts in their physical and social environment. This achievement on their part is possible only, if they leave, for a while, a part of their total teaching time the well beaten track and go on a voyage of discovey for self and others, however small this discovery may be, along with their pupils. They will find that science for the many will become very lively, exciting and even full of fun, and for the few, it will become a life-long pursuit. There is no reason why teaching and learning of science should remain at its lowest ebb in this country after independence. May be the working conditions have been and are totally dissatisfying to the majority of teachers. But a growing body of professionals is expected to investigate, like the Hawthorne Studies, the causal factors; and discover at least some sort of Gripe Mixture for making science teaching a worthwhile adventure. The truth may well come out that outside conditions, (feelings also included) influence science teaching to a greater degree than actual conditions on the job : salary and financial incentives. For example, face to face quality relationships of high order. This common adventure is only possible if as a first step, most of the members, if not all, broaden their area of professional freedom even at the cost of personal discomfort in the beginning by studying, simplifying and remedying the situation in their own characteristic ways. A broad concept of professional freedom may then emerge in this country in the near future. It is only then that the modern scientific and technical destiny of India is likely to be shaped in her classrooms in the phraseology of the Kothari Commission's Report.

—N. Vaidya

Introduction

One gets into difficulties when one looks for a single definition of science acceptable to all. It is really shocking to know that science tends to defy its own definition. For Bentley Glass, it is the 'unfinished business' a definition which stretches much beyond the concrete definition given by Prof. Percy Bridgman in which he says that science processes involve 'accurate and precise description, classification, repetition, consensus, experimentation and measurement'. For W. Pauli, it is not the fixed answers to the fixed questions (both can vary depending upon the questions to be pursued) but it is to 'attain the understanding of the relationship which connects the answer to the problem'. C.P. Snow goes a step further by saying that 'scientific culture' is not only intellectual but also 'anthropological'. 'Even the scientists do not appear to understand each other completely'! What applies to science also applies to scientific method which turns out to be a significant ingredient of the philosophy of science. The main functions of the latter are to define and redefine science concepts ; identify the various areas of scientific research which can be more profitable and productively attacked ; investigate assumptions underlying the nature of reality, and to present a coherent and consistent picture of reality based upon findings in the different branches of science[1].

Views also differ widely on what actually constitutes a Scientific Method. Some say that there is a scientific method and various steps in it can be identified and even made the specific objectives of teaching. There are others who say that there is no such thing as the scientific method. Everyone has to find his own path and in this wide context, scientific investigation is pathless with no restrictions whatsoever imposed on it! There is then no sanctity in the rigidity regarding the steps of the scientific method which have acquired a 'natural status' like the steps in problem solving with the passage of time. This is why the use and practice of scientific method does not always guarantee a solution to the problem.[2] Consider the following examples.

We still do not know how exactly the insertion of a loop checks pregnancy. All the answers so far obtained to this problem are at the hypotheses stage but the medical research is not idle on this as the material as well as shape of loops is continuously being improved upon and may throw light, may be dim, later on[3]. Scientists obtained conflicting results on the efficacy of vitamin C which were reconciled later on by the discovery that the rats possess the inherent ability to manufacture vitamin C out of the diets fed to them. About 2500 years ago, Pythagoras, a great mathematician, hypothesized solely on argumentation about the shape of the earth. Nobody took his hypothesis seriously till Columbus made a business-like use of it. The planet Uranus did not behave as predicted mathematically. The result was the discovery of the other two planets, namely, Neptune and Pluto. Even the clean, neat and highly sophisticated methods and procedures of Louis Pasteur, by which he confirmed that the living bodies always come from the living bodies, did not answer the basic problem of the origin of life. The scientists through scientific methods accepted and rejected the conflicting evidence on the nature of heat and light, the controversies which rocked the scientific world for years. Jan Vna Helmont, one of the very well-known and highly respected scientists of the 17th century, left an interesting method of making mice : 'Take slightly soiled shirts, place them on a dim, quiet corner, sprinkle with kernels of wheat and in twenty-one days one would have mice'. It was as much a demonstrable receipe as any other demonstration today for it did work in these days[4]. The Indian scientists failed to suggest a suitable dye to colour the dalda ghee. They suggested that the problem be discarded as the obtained solution may turn out to be more dangerous than the problem tackled[5]. Try, if you can separate sugar from milk sweetened by it. One should not, like a good parachuter, jump to hasty conclusions for science does not block lines of inquiry in diverse directions for all times to come. For example, if one says without reflection that nothing causes cancer and nothing can cure it, is a bad statement. It is also a bad inference in science which is likely to be challenged soon[6]. We also learn a little in this context about science from practising scientists for they also differ widely in their day to day behaviour. We only get a hazy picture of what science is from philosophy of science including scientific methods, history of science and scientists themselves, both past and practising[6].

Formulated definition of science

Science is Ideas and Techniques at Work in the Progressive Unfoldment of Natural Knowledge. According to William James, science, like life, flourishes on its own decay by discovering new facts which challenge productively its once well established rules. 'New facts burst old rules, then newly divined conceptions bind old and new together into reconciling law'[7]. It is, therefore, least surprising to know that science in its game of development loves rebels rather than conformers. The best tribute a disciple can pay to his teacher is by contradicting his Guru's work[8]. In this context, science is a great human enterprise ; not only endless and faceless but also stable and fluid. It is less complicated than an erratic lady who cannot correlate her past behaviours. So it is self-accumulating, self-growing, self-pervading, self-accelerating and self-correcting enterprise which originated in the immense curiosity of man about his environment since times immemorial. It attempts to provide an impartial body of knowledge, through objective as well as subjective procedures, which is as objective as the prevailing conditions make it, that is, do not challenge it. In every generatian, it operates in a certain frame of reference which yields to another imperceptibly gradually or even violently sometimes in the light of new observations and interpretations. It thus wheels on dogmatism, dynamism and discovery at the same time. Open mindedness, arousal and maintenance of curiosity, questioning the basis of all things (including assumptions), collection of data, demand for verification and proof, respect for mathematical arguments and logical proofs including statistical reasoning, suspended judgement, acceptance of warranted conclusions and willingness to change one's opinion in the light of new evidence are the ferments which characterize the scientific enterprise.

What is science then ? It is puzzle-solving or problem-solving or an exercise at abstracting and reabstracting knowledge and skills with a view to approach and understand the unknown. This is done through diverse ways which embrace in one form or another the so-called steps in scientific methods : Observation, problem survey, formulating and reformulating problem, setting up hypotheses and control experiments, suggesting plausible explanations, on the basis of evidence collected, finding exceptions, developing, using and refining concepts, mathematization of arguments and their application to dig new knowledge, finding principles and laws, and lastly developing relevant theories which influence our global out-look.

Illustrations from the history of science

It is the aim of science to control and comprehend environment. The scientists try hard to find sense in our environment by developing concepts and devising techniques which ultimately constitute the systematized body of knowledge called science. These ideas or concepts do not strike the scientist all at one go but have to be developed over the years. This becomes the cumulative aspect of science. In the progress of science, scientists question the current established body of knowledge at its weakest points, encounter anomalies and in the process, either suggest new subsidiary hypotheses to the same phenomena or alter the known concept radically to suit the new evidence as well as explain the past evidence more meaningfully and relevantly. Sometimes, it is just the case that they keep the count of anomalies separately which remain recognized without solution for several decades and in some cases several centuries. It takes time in science for the new evidence or concept to establish itself in the existing body of knowledge. There is thus dogmatism in science but the very change, because the ideas and techniques are at work, remains at its heart. We have discussed at depth this aspect of the problem in the fourth chapter on Science As Past Adventure. Here, we will illustrate the same with some interesting tiny examples :

(*a*) Nièpce Nicéphore, a retired officer from the French army was interested in chemical experimentation. He believed strongly that light could produce pictures of reality if allowed to fall on certain chemicals. He was not the first person to hit upon this idea. Earlier Leonardo da Vinci had designed a pin hole camera. A little later, a German monk had put a lens in the hole and produced sharp images. Nièpce Nicéphore was not satisfied with these pictures for he failed to preserve them. He searched for some materials sensitive to light which when exposed became insoluble in vegetable oils. Through hits and trials, he got hold of asphalt but the whole process of obtaining a picture on it was a very tedious job. He therefore searched for new materials and considered iodine-silver as a successful base for asphalt coating. He had little knowledge of chemistry and so he could not imagine, that he could now dispense with asphalt altogether. He was a searcher and spent twenty hard years on this complex enterprise. By chance, he now came to know Jacques Mandé Daguerre who was already working on this problem. In 1825, it is of interest to mention that his wife asked a well-known chemist named Jean Baptise Dumas whether her husband was mad or not in this hunt of the proverbial goose. Both collaborated and obtained positive pictures but the progress on the patient road to discovery was little. Nièpce Nicéphore died and Daguerre persevered alone. In 1837, he found that his spoiled plates, when placed in a cupboard for a couple of weeks, on washing for re-use had produced beautiful positive pictures. He was wonderstruck and again repeated this happening. Again he got pictures. He did not believe in miracles but in chemical means. He searched his cupboard in vain but failed to find any causal agent. He took a magnifying lens and found a few drops of mercury in the tiny fissures of the cupboard. He had moment of his insight, that is, the vapour of mercury had done the trick. He tested this hypothesis by placing plates in the atmosphere of mercury vapour in the dark rooms. Magically, the picture came on the screen. Photography was thus born. Notre Dame stepped down majestically on the plate very faithfully to be carried home by anybody. There were some enemies as well, particularly speaking, Daumier. Baudelair went a step further and declared :

> These are deplorable days in which a new industry contributes to the maintenance of stupidity and to the destruction of all that has remained divine in the spirit of France[9].

(*b*) Take another example. John Logie Baird, born in Scotland in 1888, wanted to attempt something big in life. During his childhood, he was interested in technical things. His telephone wires badly inconvenienced a coach man for which he was strictly forbidden by his father not to carry on any more excursions into the electro-technical field. He obtained a degree in physics and electricity. Due to his bad health, he could not continue on a job and therefore, started business which was again a fruitless adventure. He sold socks, Osmo boot polish, jam, Australian honey, coir fibre dust and French soap. Now he had two options left, namely, tinkering with razor blade and television. He was advised the former but he chose the latter. As already mentioned, he had bad health and on top of it, had bad financial condition bordering on starvation. He had little chance of success in this venture for the theoretical solution of the television was known for the last forty years. The whole scientific community talked of insuperable difficulties to be mastered but Baird did the trick. He carried on this self-imposed task. Consider, what did he do ?

> Baird's wash-stand became the base of the whole apparatus. It was joined by an old tea-chest, purchased for a few pennies, as a stand for the electromotor which the impecunious inventor had found on a heap of jumble behind an electrician's shop, and which was assigned the job of turning the scanning disc, cut out of a piece of card board. An empty biscuit tin was to house the projection lamp, with lenses at 4 d. each from a bicycle shop. Further ingredients were parts of a 'disabled' military wireless telegraph, some darning needless, a couple of torch batteries, some old scrap timber...all held together by glue, sealing wax, and bits of string. Around and across the whole laboratory, there was a labyrinth of electric wire.

In 1924, he succeeded to transmit the external features of a doll over a distance of three yards. He got Mr. Day interested in his future patent who paid him over 200 pounds which he demanded back soon after, for in his opinion, his patent held no promise. In 1925, he got a lucrative job at a departmental store (Selfridge) on 25 pounds per week for demonstrating his device. He left the job for he was more interested in perfecting his equipment than in demonstrating his queer piece. Again he got into extreme financial difficulties but luckily got 500 pounds from one of his cousins. Newspapers did not find a story worth publication on what he was doing. One day, he suddenly succeeded to televise an office boy who needed a half crown to obey and bear the instructions. Thus the Magic Looking Glass was born. Interestingly enough, he had to wage a war against the B.B.C. which refused to see any benefit of this discovery for the British people. He sought parliamentary intervention and was successful[10].

(c) Every school student knows that a freely suspended magnet points towards North and South. A curious student or a serious scientists goes a step further by asking himself :

Is it really true ? Let me find out ! George Grahm, a famous London Clock maker, asked himself this question. In seeking answer to this question, he was very much troubled by the London traffic which affected his observations. In the process of experimentation, he had to design a mirror and metre arrangement for making his observations very sensitive. He found that the magnet does move by a small angle. Michael Faraday was also curious about this phenomenon who attributed this small deflection to the slightly magnetic property of Oxygen. Lord Kelvin found that the magnetic variation occurs during day time only and attributed this phenomenon to sun's magnetism. Others put several other hypotheses. Balfour examined these hypotheses critically one by one and after eliminating all except one came to the conclusion that the cause of magnetic variation during the day time lay in 'horizontal electric current flowing during the day in upper atmosphere'. No crucial test to test this hypothesis was available then. Later on, part of the evidence was provided by Lord Appleton who showed that the upper atmosphere behaved like an electrical conductor whose conductivity, like the daily variation of earth's magnetism, varied with sun spot activity in the sun. Not long ago, American scientists sent rockets in the upper atmosphere; and deflection in magnetometer showed the existence of ionized gas about sixty miles above the ground. Thus the grand hypothesis became a theory[11].

(*d*) The chemists had analysed several inorganic gases, studied them and propounded the atomic theory. When it came to the analysis of organic compounds, they found that their basic concepts so relevant to inorganic chemistry failed so miserably when applied to organic substances. For example, two organic substances, ethyl alcohol and dimethyl ether, had exactly the same chemical composition (two carbon atoms, one oxygen atom and six hydrogen atoms) but different properties, that is, one is a gas and the other a liquid. Why this anomaly ? Berzelius then propounded that the Chemistry of Living Things was something different which had its own subtle rules. In his opinion (firmly held and shared by many chemists of the day as well), only living bodies could produce organic compounds. In 1828, Friedrick Woehler prepared an organic substance in the laboratory by heating ammonium cyanate. It, on further testing, turned out to be Urea, a component of Urine. It was impossible, according to the tenets of Berzellius because human kidney was necessary in the manufacture of Urine. Woehler repeated this experiment a number of times before he made his discovery public. Interestingly enough, Berzellius and other well-known chemists of the day refused to trust this discovery. But more confirming evidence from other chemists poured in. Thus same laws applied both to inorganic and chemistry. Only the configuration of atoms was different[12].

(*e*) It was in the year 830 that Geber discovered that three substances, iron, lead and copper gained weight on heating. The fourth element to the list was added by Lord Robert Boyle in the seventeenth century. And it was in the eighteenth century that Lavoisier supplied the true interpretation. His laboratory observations, during the process of reconciliation, led to the discovery of chlorine and carbon monoxide. He spent thirty years in recording faithfully barometric readings for identifying clearly the variables which affect weather. He heated water for not less than 101 days in a special type of flask (Pelican) to refute the theory held for several centuries that water was transmutable into earth. This was despite the fact that Lavoisier had ill health as well as other official duties[13].

It appears that ideas in science sooner or later appear to reach an edge. Newton discovered the composition of light when he found that measured dispersion inconsistent with the Snell's law discovered earlier. The electric battery was conceived and developed when existing detectors of electric charges failed to behave in the context of Franklin's paradigm. Uranus did not behave as predicted mathematically. So this led to the discovery of Neptune; and, later on, of Pluto. The small but persistent anomaly in the measured density of nitrogen led to the discovery of nobel gas, then, considered non-reactive. The anomalous properties of conduction led to the motion of electron which acquired spin, later on, to explain the then existing anomalies observed in atomic spectre. Strong electrolytes like common salt and sulphuric acid contradicted the Theory of Electrolytic Dissociation right at the time of its origin in 1887 by Arrhenius. Chemists did not bother the least for they remained (strong electrolytes) anomalies for not less than thirty years. Physicists did not reject the quantum hypothesis when the laboratory value of the specific heat of hydrogen did not agree closely with the one obtained from quantum theory. They instead tried a subsidiary hypothesis assuming the existence of two states of hydrogen. This removed the anomaly. This is the way, the investigative way along which the hypotheses are set up, tested and reformulated (and even combined) that an objective body of knowledge results.[14]

What applies to science also applies to engineering to a varying extent. But, generally speaking, the engineers are quite oblivious of the assumptions made by mathematicians and physicists in their theoretical derivations. For example, without suffering any theoretical inconvenience, the engineers can draw a straight line on earth without defining it. They have to do so for they have to solve the practical problems. Metallurgists, for example, find information on the chemical composition, tensile properties or hardness of a given alloy inadequate. They do not feel dejected because they supplement this information by supplying its entire manufacturing history, for its varied utilization.[15] In conclusion, all the above mentioned examples illustrate the theoretical as well as the practical difficulties with which scientists and technologists have to live with. They do not at all discard the complex problems straight away which appear too opaque for them at the beginning. Instead, they reexamine them at depth and pose them in their solvable forms with a view to master the consequent difficulties gradually.

Illustrations from classroom experiences

It is a poor application of science if it is raised to a slogan: Science Is Doing. There are other aspects to the spirit of science (discussed in the second chapter) which are more important than doing (or merely bottle washing) for here the manner of doing is to be guided by the hypothesis setting and testing approach. It is possible for the science teachers to find many growing points for the development of a large number of scientific concepts in their physical and social environment. The author engaged fruitfully eleven year old British children and fourteen years old Indian children on Benefits of Electricity to Mankind; and The Foods We Eat, for not less than three months each.[16] The British children recorded not only the benefits of electricity but also the electrical devices they have (or had) used, seen and heard both at home, in the community, and at school. They were goaded to see most of them from inside, draw pictures as these looked from inside, and classify them on the basis of Four Effects of Electric Current. Discussion then centred on the production of electric current which incidentally led to the manufacture of atomic and hydrogen bombs. Students set up several experiments for demonstration which, in the process, led to fabrication of equipment. Then they felt the need for knowing about Ohm's Law, Laws of Resistances and Wheatstone Bridge.[17] The Indian children were equally enthusiastic. They noted all the foods which they ate, including drinks. The question then arose: Why do they eat only these particular foods ? Immediately, it became possible to classify the entire group into vegetarians and non-vegetarians. It became difficult to continue with the lesson for the discussion immediately led to religious issues. The variety of foods eaten by them were then analysed into the main constituents of foods; Carbohydrates, proteins, fats, vitamins and mineral salts. A chart of cheap foods in the context of above mentioned constituents was also prepared. Many other side problems arose regarding balanced diet for different age groups. Interesting discussions but without basic education and visible impact took place on Substitute Foods and Change of Food Habits. The whole atmosphere was free and so were the enquiries. Text books and reference books became inadequate for it became increasingly difficult to find definite information on some foods eaten in certain parts of the country. These youngsters gave a tough time to the then Deputy Director of Education, Delhi (who closely questioned them on foods) by telling her that Vitamin D was not found in sun rays for it could not be extracted straight away from them.[18] It is only in few of these ways that the classroom captures a bit of the reflective atmosphere. School then becomes to a certain extent the Centre of Inquiry where children go on learning, unlearning, and relearning without suffering constipation due to massive dose of information. Take other examples.

(*a*) Jackson gave his students a piece of unknown metal to investigate (tin). His students had not been at all introduced to formal chemical analysis. They used their available knowledge in chemistry and in the process employed unorthodox methods which turned out, largely speaking, to be successful.

Use of reference texts was allowed. To quote Jackson :

> Most of them started by determining the density, and thus discovered in which part of the periodic table they should concentrate their research. So they now tried a series of displacement reactions, whilst others made a series of cells against known electrodes. So they knew its position in the activity series. Then and only then did they commence more orthodox chemical reactions—What was the effect of heat, could it be oxidized, how did it react with chlorine, and how did it behave with acids and alkalies ? The majority concluded that the metal was tin. All of them knew that it was a metal of density 7.3 which was more active than Copper and less active than iron and zinc, and all could give a reasonable summary of its chemistry.[19]

(*b*) In another classroom, the teacher posed his students several sub-problems. One of them was to 'investigate the relationship between time and the area of the hole'. The students were free to choose methods of investigation relative to their problems. They were asked to return after they had solved the problem. Again, it is a discovery for these four students because they are thrown to their resources to tackle this problem. For example, they have to think of going to tin-smith section for getting holes of known diameters punched in tins. They have also to think unaided of apparatuses likely to be required in this experiment. They have then to record results of several pourings which were as follows :

Diameter d in cms.	1.5	2	3	5
Time t in seconds	26.7	15	6.8	22

The problem does not stop here. The problem solvers have first to feel or suspect the likely relationship qualitatively. They suspected the relationship rightly and drew graphs between t and d, t and 1/d, t and $1/d^2$, and saw the types of curves obtained. They even went to the extent of extrapolating these curves for answering other questions. By getting another tin, they verified the graphical value. Other factors were varied and the attack on the problem continued[20].

Knowledge of facts alone is not sufficient. More important is how facts are used by growing children. One of the easiest ways is to help students raise questions and find their answers. Of course, time is lost but it is better to lose time in the beginning than in the end for a stitch in time saves nine as the saying goes. The framers of the Science Curriculam Improvement Study (SCIS) have gone a step further by suggesting three types of lessons, namely, exploratory, invention and discovery. They are based on the basic notions of Jean Piaget who states straight away without mincing words that a teacher cannot give a concept to his pupils. The latter have to be involved in first hand experiences before they can develop their cognitive structures. These cognitive structure grow with repeated use in as many diverse situations as possible. In the first type of lesson, they explore the natural environment. They will play, say, with mirrors and lenses. They will thus gain several types of facts and concepts perceptually which are not to be strictly evaluated so far as their accuracy is concerned. In the second type of lesson, the teacher will guide them to see the basic underlying concept as was invented by the scientist. At this stage, he won't forget to introduce a minimum amount of new words (scientific vocabulary), facts and concepts. This is important because, at this stage, the pupil will see and find sense in many of their conceived notions gained during their extensive encounters in the first type of lesson. It provides a framework rather than a list of basic concepts to be crammed for the examination. Teacher's assistance here becomes critical in the sense that the manner of formation of these concepts defined operationally is very important. It is this quality of the concepts formed which will be tested in the third type of lesson, namely, discovery. In these type of lessons, the pupils get abundant opportunities to apply their knowledge. The lessons 'stimulate autonomous recognition of relationships', broaden background knowledge for current and future use, reinforce knowledge and skills, and lastly, motivate them towards self education. Convergent thinking appears to be the distinguishing characteristic of the second type of lesson whereas the third type tends to encourage divergent thinking in a big way, that is, in an open ended manner.[21]

Focus on investigative projects

Indian students are inferior to none in the world. It is not that they are being undereducated but they are being miseducated on a large scale. Foreign experience at least clearly tells the author that European children would not have behaved differently or fared better than our young boys and girls in similar circumstances. The former in frustration would have not only kicked their teachers outright but also burnt their science laboratories. It should not be forgotten that, not long ago, in England science was prescribed to those who had feeble minds or hard heads and clever fingers' (Eric Ashby). We are more fortunate than them in this respect in our country. The solution to our problems in the area of science education lies in concentrating more on substance rather than shadow, more on formation rather than information; and more on the development of scientific attitudes and skills rather than on down-grading content unreflectively. The question then arises : How can we do this ? The answer is by attempting part of the syllabus in an investigatory manner. Successful experiences thus gained should be utilized to tilt the balance favouring the achievement of modern objectives of science teaching. It should be borne in mind that what applies to science also applies to other school subjects. So there has to be a systematic attack on the Mechanical Habits of Thinking among pupils by all the teachers otherwise the result of our efforts would amount to Stretching an Elastic String.

It is difficult to find a hard and fast definition of Project in the literature surveyed in this book. One always anticipates difficulties inherent in this exercise. But still, it is possible to make the meaning clear, as far as possible. It is just like telling more about a Hindu who is neither a Muslim, Christian, Parsee nor a Sikh. Or a Railway Time Table is not a piece of English literature despite the fact it is a big book. The same thing applies to the definition of Project. It is neither an essay, an experiment, demonstration nor an improvised equipment or a table of observations alone. If we go a bit further, answering a question also does not define a project (what is your name ?). But at the same time, all these are the ingredients of a good project. One has to encounter a problem (even several problems) repeatedly. One has to formulate it as sharply as possible so that it could be managed. One has to set up hypotheses and test each of them under controlled conditions. How to test them becomes a problem of designing controlled experimentation as well as finding working materials as well as acquisition of new techniques. This is a function of what sort of data to seek and collect for answering the aims of investigation ? One has then to collect the relevant data quite carefully with little outside interfering factors. Now comes the moment for the investigator to draw reasonable inferences or interpretations. The investigator does not stop here. He has also to evaluate the interpretations as well as suggest other subsidiary projects unless it is the last word on the project. Searching a problem, solving it experimentally, theoretically or both and suggesting other problems are the three significant pupil behaviours which come on the top while elucidating the meaning of Project. This applies to experimental problems. There are other type of projects as well. Examples are finding conceptual flaws in a given text book, suggesting another solution of the same problem, finding limitations or new problems, developing theoretical solutions for practical problems, selecting suitable problems for investigation from the history of science (going beyond strict documentation), documenting research on current research in a given area, and several others from applied sciences and engineering. A project is, therefore, an attempt to tackle a theoretical as well as a practical problem, systematically. The manner of systematization or method of procedure is the product of an individual projecteer's mind and his environment. This is the reason why an unsuspected method of procedure after it yields a successful solution becomes a part of scientific methodology in which different scientists choose and use methods and procedures relative to problems under study; and hence we consequently talk of scientific methods rather than scientific method alone[22].

Functions of investigative projects

Both tangible and intangible benefits result, when science students begin to undertake investigative projects at school. They know first-hand what it means to tackle a problem experimentally as practising scientists. Secondly, they begin to assimilate classroom instruction reflectively rather than absorb it like a sponge. Thirdly, they begin to familiarize themselves with research tools. Fourthly, they begin to learn how to tackle difficulties and seek varying levels of acceptable solutions under the existing conditions. Fifthly, they begin to show gains in several personality traits, for example, perseverance, emotional stability, self-confidence and co-operation etc. Sixthly, they learn to admire the work of past workers who gave thought to complex problems. Seventhly, possibilities rather realities begin to dominate their thinking. This is why the role of scientific attitude is more critical than the role of massive dose of information in the basic education of our boys and girls. Lastly, they begin to learn to pick up independent habits of thinking and working as well as develop friendship with the School of Difficulties not only in the world of science but outside of it as well. And this leads to self-education, the chief distinguishing characteristic of any first class educational system any where in the world.

Features of investigative projects

It is evident now that projects generate new experience and knowledge for pupils much beyond the textbooks. It is just possible that some of them may stumble against certain original problem bordering on intense curiosity. They may as well discover original facts like Galelio who found that the period simple pendulum depends strictly on the length of the pendulum before he had entered the university. It hardly matters if they discover new facts with wrong interpretation (It was found much, later on, that Galelio had discovered moons rather than any other hitherto unknown planet). The features mentioned below may be only considered suggestive rather than prescriptive for the very reason that the authoritarian principle does not work in the domain of science. Lastly, unnecessary and unimaginative restrictions with a view to get quick results kill the very soul of science. In this context, the following features of investigative project are suggested :

(*a*) It should illustrate a scientific or principle from the pure or applied sciencc. There is no ban on including other branches of knowledge like psychology, history, economic development and even the history of science involving precising and documenting.

(*b*) It should involve some scientific experimentation and reflect the development of some scientific skills to a remarkable degree. To put in other words, it should show some forward thinking and action on the part of the student which goes much beyond the conventional text book and laboratory exercise.

(*c*) It should make use of, largely speaking, inexpensive materials easily available in the environment. One should not finish with the improvised apparatus but, on the other hand, sincere attempt should be made to use it as a vehicle for further investigation including verifications, say of physical constant.

(*d*) It should be neither too difficult nor too easy. If it is too difficult, it is not likely to be attempted. If too easy, it will lose much of its charm and function. In fact, attempt should be made to select projects in keeping with the mental development of children. There will be also then no problem of motivation.

(*e*) It should not take unnecessary long time to complete. Otherwise due to the various demands made on the pupil's time, the project may be left in disgust, and lastly.

(*f*) It should be well constructed for display and attention getting. For this very reason, it should be quite durable[23].

Science teaching in our country despite our best efforts to improve it, is in a very bad shape. Our students pass their examination but they are not all familiarized with the nature of scientific enterprise. We thus fail to build quality into our science teaching for the very reason that innovation and research are not built into it. Investigative projects, thus, show great promise in overcoming the main deficiencies of science teaching. Our experience at the science youth project clearly demonstrated that investigative projects need not be very costly for a vast majority of pupils. If carried out in the right atmosphere and spirit, work on the projects is a transforming experience both for the students and teachers in posing problems and seeking their solutions at depth experimentally. We can thus succeed to impart training in scientific methods using cheap materials. If suitably bent, the completed projects can supplement and enliven day to day classroom teaching. If carefully cultured and nurtured through proper guidance and follow up, investigative projects will surely turn out to be an Impact Nucleus; away from stressing memory, in learning science with the inherent potentiality of changing the scientific and techonological face of a tradition bound society having 'two big majorities of the poor and the young'. Here, the role of teacher is critical. Neither the grades of the Kothari

Commission nor the borrowed consultants and equipments from abroad can solve our problems if majority of the science teachers lack will and imagination to visualize the kind of work they are supposed to perform at school. Like Hawthorne Effect, it may just well turn out that there is no direct relationship between facility and efficient science teaching. The development of face to face quality relationship may do the whole trick. Positive attitude to work rather than dissatisfying working conditions may turn out to be a more important factor. Conditions and feelings outside the job may turn out to be more critical than the actual opinionated conditions on the job. We have not forgotten the students here. They may offer extra co-operation if they find that their teachers are taking more interest in them than is generally the case. Teachers, who have worked freely with their pupils, report wonderful experiences. Quite unbelievable ! In fact, the pupils have led their teachers for the formers did not know the end points of their investigations. The latter knew and therefore had to dampen their enthusiasm reluctantly with a strong foot down for the fear of their failure in examinations. It is questionable whether this practice is desirable or not when they are in a mood to master the stimuli rather than the restraints. It is, of interest, to mention here the case of Professor Harold. C. Urey who, at the age of fourteen, got one mark more than the pass mark to go to the high school. He would have failed had he obtained one mark less. He won a Nobel prize for discovering heavy hydrogen by hypothesizing its existence on the basis of carefully and accurately found atomic weight measurement of hydrogen and oxygen which, later on, were found to be in error[24]. Had he been born in India, it is just possible that a man of his calibre evaluated poorly by the examiners would not have qualified for the post of Chemistry teacher at school. In depression, he would have opted for something else. Nobody can deny that we do not have Ureys among our young projecteers in our vast population of young boys and girls at school. Like oil, they remain buried under the ground. So it is another method of losing talent, according to rules, unknowingly with incalculable loss to the growth of futuristic first rate scientific community in our country. Consequently we remain poorer to the extent this loss takes place every year.

2. *The Nature of Scientific Enterprise*

(i) A sense of design and order, and a delight in classification and system, is characterstic of civilised man. In all branches of art—music, painting and all the plastic arts, poetry, architecture—we see deliberate grouping and ordering, a putting of certain things together as a balanced whole. The justification for the way in which the arrangement is carried out, for the method according to which the notes are arranged in a sonata, for instance, must be sought in some innate character of the mind, in something that may be called an aesthetic sense, for want of a more precise term. The artist in his arrangement and juxtapositions is concerned with subjective things, with personal feelings, beliefs, sensations and inner convictions, and no body can bring anything approaching a proof that he is a wrong-minded or a bad artist. The only appeal is to canons of taste, to the accepted opinions of practitioners and critics, which may be widely divided, while even the verdict of the majority will vary from age to age, and from clime to clime.

Science does not differ from art in being an ordering and arrangement, nor, inspite of widespread belief, is the man of science deprived of the aesthetic satisfaction that a well balanced piece of work gives the artist. He can often with justice speak of a beautiful experiment, even if all that is observed is the movement of a spot of light through a measured distance, of an elegant deduction, and of a pretty proof. It is in its subject-matter in its criteria of truth that science differs from art and, for the matter, from philosophy, as the word is understood nowadays.

The subject-matter of science is the body of observed facts of Nature, and the test of the truth of a deduction is its agreement with experiment or observation. In art, the masterpiece of one generation may be derided as worthless by the next : in philosophy, a beautiful chain of reasoning can claim merit even when it makes no appeal to any such hard facts as are the subject of general agreement. In science, however, the achievements of one generation represent something won from Nature which remains as definite gain and definite progress : an experiment properly carried out remains for all time. The most ingenious agreement has no validity if it leads to a result which is contradicted by experiment. The sense impressions of the external world are the ultimate court of appeal, and the innate sense of the fitness of things, which may vary from person to person, and from school to school has to yield to observation of what lies outside the observer. There is in science no book or court or canon to which all difficulties can be referred, except the book of Nature. There is no appeal to the emotion nor invocation of agencies lying outside laws deduced from the experience of many independent observers.

—E.N. da C. Andrade

(ii) The field of science is unlimited, its material is endless, every group of natural phenomena, every phase of social life, every stage of past or present development is material for science. The unity of all science consists alone in its method, not in its material. The man who classifies facts of any kind whatever, who sees their mutual relation and describes their sequences, is applying the scientific method and is a man of science. The facts may belong to the past history of mankind, to the social statistics of our great cities, to the atmosphere of the most distant stars, to the digestive organs of a worm, or to the life of a scarcely visible bacillus. It is not facts themselves which make science, but the method by which they are dealt with.

The material of science is co-extensive with the whole physical universe, not only that universe as it now exists, but with its past history and the past history of all life therein. When every fact, every present or past phenomenon of that universe, every phase of present or past life therein, has been examined, classified, and co-ordinated with the rest, then the mission of science will be completed. What is this but saying that the task of science can never end till man ceases to be, till history is no longer made, and development itself ceases. The goal of science

16716

is clear—it is nothing short of the complete interpretation of the universe. But the goal is an ideal one—it marks the direction in which we move and strive, but never a stage we shall actually reach. The universe grows even larger as we learn to understand more of our own corner of it.

—Karl Pearson

SECTION A

Impact of science and technology

Science, engineering and technology, now considered synonymous by laymen, are in the news. It is no wonder then when it is being said with a great bang day in and day out that we live in the age of science, engineering and technology. There are reasons for this because there is hardly a village of significance over the globe where the fruits or products of science in one form or another have not entered. It is a fine human achievement which became possible, largely speaking, on account of the intensive application of pure scientific research made in the nineteenth century. Imagine the consequences! Distance and time stand fully annihilated. Atom, electron, nuclear fission, radio physics, biophysics, biochemistry, radio chemistry, synthetic fibres, newer and newer drugs, discovery of revolutionary building materials and techniques, atom-smashers, computers, communication satellites, electron microscope, and lastly, the space travel (the fantastic adventure of man in space!) have become house-hold words. They have stimulated our thinking profoundly but with little change in human outlook. It is the least surprising then that we live not in one age but in several ages at the same time in the same century : computer, automation, space, atomic and power. In case of developing countries, apart from iron, steam and electricity ages, we can safely add two other ages, namely, bullock cart and cowdung ! Really speaking, they appear to represent all centuries if remote areas in the developing countries are also taken into consideration. This biting situation is natural because they missed the first Industrial Revolution for reasons beyond their control. By developing science and technology indigenously as well as borrowing it from the friendly developed countries, they are now trying hard to eradicate by telescoping their age old intellectual, social, economic and political backwardnesses within a few decades. These efforts at all round improvement originated some time in the late forties. This successful global effort has now become possible due to rapid strides made in the field of science and technology over the last forty years or so. For example, take the case of computer, not muscular but electronic in character, which has become a very powerful servant. With its complex growth in several directions, it is successfully tackling increasingly complex and complex problems considered to border on impossibility at some time in the recent past. As late as 1963, a computer could solve several thousand calculations in one second or so. To quote Paul D. Hurd :

> Recently a new computer, the LARC, was put into operation. It can add or subtract 250,000 12-digit numbers in a single second. Its cathode ray output can flash the result of these calculations at the rate of 9600 lines of type per minute. In one hour, the LARC can do the work of forty men working with desk calculators forty hours a week for one hundred years. The construction of this machine was so complicated and the circuitry so involved that it was necessary to use another computer to assist in the design of the instrument. With the LARC, it will now be possible to attack mathematical problems more complex than man has been able to solve before. Recently the organisation of an entire chemical plant was designed by a computer[1].

It is interesting to note that it became outmoded in a few years time because now there are several superior ones available in the market. We should not foreget that it was through computer alone that the man's successful historical flight to the moon became possible. It was a big triumph of engineering ! Several changes in his environment, and discoveries announced quite frequently are completely irritating, if not baffling, the twentieth century man. Some of the changes are beneficial beyond measure. It is now within the domain of possibility to manufacture synthetic and electronic spare parts for human body, to press biochemistry into service to grow even new organs and limbs, to produce drugs which raise intelligence remarkably, to control undesirable hereditary traits in humans, to halt the progress of aging processes with a view to increase the average span of life, and lastly, to enlarge man's intellectual functioning with the help of a computer. Peaceful atom has thus become a source of just short of infinite benefit to mankind. All this amounts to saying that given the intelligent control, comprehension and direction, it is no longer a practical impossibility to satisfy fully the age old essential requirements of food, shelter and clothing. It is now becoming increasingly possible to eliminate human misery and want, hunger, famine; and even war—may be on the balance of terror like the putting of two deadly scorpions in a bottle capable of harming each other more or less equally in the phraseology of Robert Oppenheimer, the father of the Atom Bomb[2]. In the seventies, it will be possible to provide quality education to all children of all people by using electronic gadgets, teaching machines, language laboratories and communication satellites. These endless advantages accrue to us from the intensive cultivation of science and technology—giving us, practically speaking, a 'fantastic, push-button dream world' of leisure, luxury and license. In fact there is a danger that it may not become a kind of 'gigantic Disneyland in which the human race with perpetual happiness playing with an endless assortment of even more assortment of evermore ingenious mechanical toys'[3]. Is this not the wildest optimism ?

But at the same time, there is the worst fear and pessimism overtaking us all that we may not live to see personal, collective and global bright futures. A disturbed and destructive atom along with an erratic computer under political misadventure may explode the whole world to its absolute wretchedness within a flash of second hitherto unthought and undreamt of by humanity during its entire march to progress since recorded history. To quote Herbert W. Armstrong and Garner Armstrong :

> Today's world looks with awe at modern science as the Messiah trusted to deliver it from poverty, ignorance, disease and unhappiness—to solve all its problems.
>
> Science and Technology, teamed with Commerce and

> Industry, promise, by 1975, the magic push-button dreamworld of leisure, luxury and license.
>
> But modern science has failed utterly to reveal to the world the purpose of human life or explain its true meaning. It remains ignorant of the true values. It does not know the way to peace ! It has failed miserably to deliver the world from poverty, famine, disease, fears and worries, unhappiness ! It has not rid the world of broken homes, crime, insanity, immorality. Rather, all these are on the upward spiral.
>
> A realistic look at the fruits of modern Science leads only to disillusionment ! Science and Technology confine their attention to the realm of the material and the mechanical purpose and meaning of human life. The true values ? basics to human welfare are not their concern ! These essentials are outside their field.
>
> Look again to their fruits. True enough, we find accelerating invention and production of intricate mechanical devices, labour-saving mechanisms that inspire awesome admiration and spectacular entertainment and amusement devices.
>
> But, then, we also observe that people have not been taught to put added hours, days and weeks of leisure to beneficial uses. The fruitage here is increasing idleness, aversion to the happiness of work, covetousness, desire for more and more—and dissatisfaction with it when it is acquired ! These turn out, in practical application, to be false values, which only increase unhappiness. An increasing segment of adolescents, with money to spend and nothing but idleness on their hands, become frustrated, staring a hopeless future in the face, turning of immorality, violence, and—too often—suicide ! The leaders of tomorrow in this world are becoming the 'beat' generation !
>
> And, after all, the principal contribution of modern Science and Technology has been the production of constantly more terrifying weapons of mass destruction. Push-button and destory two whole continents, probably culminating in the total extinction of mankind !
>
> Modern Science stands exposed as a false messiah—The Frankenstein Monster threatening to destory us all[3].

This is nothing but simply a highly disorganized situation in which we find ourselves. It tends to threaten increasingly both man and his abode. It is, really speaking, a qualitatively and quantitavely a more nervous reaction than the ones when X-rays were accused of photographing man from within, that is, the skeletal structure; and light added to light produced darknesses. It is, of course, true that every scientific discovery has evoked varying degree of intense emotional reaction or concern against it. Society, however, accommodated to them for they were a few and far between. Both physical and verbal violence did result but the better sense prevailed. Had this not been so, our present day material culture or civilisation would have been impossible ! The situation in our times has changed radically enough. Just imagine and analyse the attitudes of our Public undertaking employees toward automation or computer. In the face of communication failure, and education, any thinking human begins to see the problems of the modern age or the process of accelerated modernization. In a restricted sense, we have to find answers to the following questions based upon collaborative understandings, skills and attitudes :

(i) What should be the exact role of science and technology in the planned development of society, materially speaking, in all its aspects ?

(ii) Up to what extent is the education of man through Science and Technolgy possible ?

(iii) What should be the regional, national and international scale for expenditure on Science and Technology taken both collectively as well as individually ? What about the claims of humanities and other social sciences in this enterprise ?

(iv) Who should control expenditure on sciences and technology ?

(v) What should be the pattern of relationship between science and technology on one hand; and government on the other ? What about the individual scientists' freedom in choosing his problems which he regards fundamental ones for the progress of science ? (There are other allied problems which relate to scientific secrecy, misadventures of individual states in the militarization of science, public relations role of scientists towards science and scientists, and the moral responsibility of scientists).

(vi) How to reap the Big Harvest of the second Industrial Revolution ? How to tame it and press it into service for the benefit of the mankind? Discovering this dimension in the midst of our complex difficulties can be as exciting as scientific research. The great eighteenth century German Philosopher possibly hinted at this problem, worthy of solution, by the greatest minds when he pointed to the significance of galaxies in the universe. Immanuel Kant said, "Two things fill the mind with ever-increasing wonder and awe, the more often and the more intensely the mind of thought is drawn to them: the starry heavens above me and the moral law within me"[4].

The above mentioned problems do not cry for halting progress in science and technology, that is, Full Stop Leading the Sentence Type of Solution as is generally offered in the popular press. But, on the other hand, these very nerve-rattling problems need to be re-examined and reformulated more and more productively with a view to clarify as well as seek acceptable solutions. Here, the only fact in our favour is that scientific and technical discoveries have no minds and prejudices of their own, that is, they are fundamentally neutral just like the live electric wire. One can get either an electric shock or a beneficial magnetic field depending upon one's degree of ignorance or enlightenmet. This book does not attempt to tackle these problems but only present them in perspective for those who intend to develop friendship with the Nature of Scientific Enterprise. On the other hand, it attempts to tackle a limited problem, that is, the theoretical and practical foundations of student investigations in science. Let us now consider the role of science education.

Role of science education

A large number of problems have been raised in the preceding pages. In this context, the role of science education also becomes critical because science and technology have become the growing edges, about nine times more than usual, of our society. These are influencing our lives and environment (material as well as cultural) in so many diverse ways. This, unlike in the past, makes it imperative that science education should play a critical role of the conceptual variety in the basic education of our boys and girls right from their early childhood onwards. Not long ago, Karl Pearson in his book on Grammar of Science emphasized the importance of 'training the mind to an exact and impartial analysis of facts' with a view to develop sound citizenship and international relations universally[5]. This goal is not being even partially realized due to many reasons in which we need not go despite the sterling fact favouring us: In order to pay Paul, you no longer need to rob Peter! Failure to understand this contribution of abundance bestowed on us by Science and Technology in modern times, has resulted among all nations of the world in scientific illiteracy on a large scale, even the highly developed country like the U.S.A. being no exception (Fitzpatrick). The situation appears to be present equally pessimistic in England when the Observer says: 'Our education process is comparable with a sponge, absorbing standardized information and squeezing it out again in examinations. Most of the education, children get between the ages of 5 to 18 is culturally and vocationally valueless and useless'[6].

It should not be lost sight of that England not only tries hard to impart education to its embryo citizens according to their age, ability and aptitude but also succeeds to provide the highest degree of specialization in the world in the Sixth Form, the last two years at school. The situation is much worse in the developing countries where sound programmes of science education have yet to stem from our clerical tradition of education. Thus there are problems for every-body everywhere: laymen, teachers, scientists, industrialists and politicians. With special reference to the teaching of science, teachers must deeply arouse the curiosity of thier pupils, help them to think logically and critically and develop problem solving skills, scientific attitudes, scientific interests, intellectual admirations, and responsibility for seeing the relevance and use of advancing scientific knowledge in the betterment of man and environment. Unlike Faraday and Davy, the present day scientists find themselves in a queer position. Most of them fail to interpret their abstract ideas to the masses as well as to see their own speciality as part of the cosmological knowledge. The tasks of the engineers and technologists are too specific and hence they fail to understand the real nature of their jobs. They have to learn to formulate and translate philosophical values into technical tasks and accomplish them. For politicians, the problem of setting one nation against another or to fish into troubled waters is gradually disappearing for it is now becoming theoretically possible to share on collaborative bases the full benefits of the second Industrial Revolution. The politicians everywhere influence policy decisions. It is, therefore, very imperative for them to lend a helping hand in the development of scientific temper among their people who, in turn, can then cope successfully with day to day modern problems of living in a heavily weighted society of science and technology[7].

Functions of science education

Many statements appear in literature regarding the aims and objectives, functions and central purposes of science education. These usually begin somewhat as follows : helping students to observe intelligently etc., arousal and maintenance of curiosity development of scientific skills, interests, attitudes and appreciations, and the betterment of man and his society at large. Robert Sonne Cohen in his paper on Individuality And Common Purpose has stated the following values and goals for science teaching. These are :

(i) To provide enough understanding to enable the educated citizens to collaborate intelligently with those who are actively engaged in scientific pursuits.

(ii) To enable the citizens both to criticise and to appreciate the effects of the sciences on his society to understand its history and to present alternative prospects.

(iii) To give a practical grasp of scientific methods of grappling with problems, at least, sufficient for problems which the student will face in his individual and social life.

(iv) To help the pupil and citizen to understand the whole world better factually; and especially the world as it affects him concretely. He should not be a spectator of the mysterious doings of scientists or of their products.

(v) To kindle enthusiasm for the intrinsic delight of scientific knowledge; in part because it will make life more enjoyable in past because society has an extreme need of good scientists in every field of human difficulty.

(vi) To understand the place of science among other intellectual and aesthetic pursuits : briefly, to see the science as being themselves a humanistic enterprise, as much as literature, the arts, history and religion, connected closely with them while differing from them.

(vii) To help the pupil who has already chosen to become a scientist, technician, or engineer to comprehend the humanistic basis and significance of his life—speciality and to overcome the ever-present danger that we may, in our schools and colleges, produce a specialized and narrow-minded technician, whether in the research laboratory or in the machine shop or at the factory bench, and to teach him humility in his role as scientist, serving, not dominating society.

(viii) To help the citizen investigate ways of increasing the range and depth of understanding natural processes and to relate this problem of encouraging and exploiting science to the many puzzling complexities of industrial society.

(ix) To provide our students with rich and various experiences of individual thinking and critical attitudes on the one hand, and of cooperative enterprise and mutual aid on the other.

(x) To help the pupil to understand the position of his future job or activity in the productive web of society as whole, technically and scientifically as well as socially, so as to establish his name and healthy self-knowledge and so that he may act more intelligently with others whenever there are joint undertakings ; and lastly,

(xi) To educate our students so that they may distinguish ends from means, probabilities from certainties, evidence from propaganda, questions from pseudo-questions, rational belief from superstition, and science from quackery[8].

These values look grand on paper ! The problems arise when they are to be translated into meaningful tasks. Any worth-while programme of science education ought to reflect these values through a series of planned experiences and individual and group projects of varied types. Unlike history and literature, science is a neutral medium in which little emotional tones of national jingoism and the beastly emotions are involved. There is no appeal to the higher court as happens in civil and criminal cases as the only court of appeal in science is the Book of Nature. Science teachers can thus easily achieve the basic objectives of humanity. It will be a case of great criminal negligence on the part of science teachers if they fail to light the constructive imagination of their wards in the wake of scientific and technical revolution going on in a big way in our times. Further, they have to nurture high scientific and technical ability possessed by a few of their wards. High examinations marks are necessary but not sufficient indicators of highest scientific acumen. They lie all along over a wide I.Q. range. A future man of science, contrary to popular belief, is always compelled to think, imagine, speculate and consult the big Book of Nature when he begins to investigate and disclose in bits the mysteries of nature. Science thus ceases simply to be a fact-gathering activity for facts themselves frequently become highly controversial. Keeping this in mind, it is of utmost concern to all of us to see our abstract philosophical values like truth, beauty, goodness, equality, liberty, equanimity and abundance translated into worthwhile educational and technical tasks, submerging in the process, local tensions and regional conflicts. These educational and technical tasks help us see the personal and impersonal problems in a wide frame of reference. Thinking and acting towards these objectives will lead ultimately to the Materialization of Values (Herbert Marcuse). Perhaps it is only then that the moral fibre will emerge up the Nature of Scientific Enterprise 'illuminating the values and purposes of life'.

Assumptions underlying science education programmes

Children are outdoor creatures by nature. They are full of life, enthusiasm and curiosity. They have sense of wonder and awe. They enjoy both fun and being funny at times. In short, they are alive, and interested in all sorts of things in their immediate environment. All these factors need necessarily be taken into account while developing a meaningful programme of General Science Education for them. It is only in this context that they must be trained to ask relevant questions and seek answers to them. We should not see their work solely from the point of view of research scientists. Let us now mention below assumptions underlying any significant programme of science education :

(1) Every normal child encounters many diverse problems. A few of them, he regards very fundamental, significant, worthwhile, relevant and meaningful in the light of his personal needs, capacities, capabilities, interests and past experience.

(2) Most of these problems when collected and classified for a given group of children appear to stem from significant area of human living.

(3) Children remain fundamentally alive to their proximate environment through self explorations, rich experiences, directed observations and even the practice of control experiments. On further analysis, common patterns of reactions appear to emerge despite characteristic individual perceptions.

(4) Given the free climate where children can commit intelligent and useful mistakes, they tend to make effective and intelligent use of their evolving concepts in discovering new knowlege. They can be thus easily stimulated to :

(i) Phrase and rephrase pin-pointed problems for investigation at depth;

(ii) Suggest sharp hypotheses, test some of them and give a few likely explanations;

(iii) Set up control experiments with a view to distinguish clearly between relevant and irrelevant answers;

(iv) Draw reasonable conclusions from control experiments;

(v) Think out and suggest likely reasons for any conflicting evidence, if came on the way; and lastly,

(vi) Feel the sense of achievement and purpose.

The above statements provide a key frame work. They gradually introduce youngsters to Research Operations. At a later stage, they automatically or reflexively learn to attack problems specifically, investigate them systematically, execute relevant experimentations intentionally as well as intuitively, and even ponder over conclusions reflectively. They also learn to be sensitive to the problems on the way as well as to any chance observations.

(5) Unlike adults, psychologically speaking, children do not appear to suffer from any fixedness in ideas or approach. They can see the same problem afresh without undergoing any discomfiture. Thus, as already mentioned, they continue to improve and refine their scientific concepts and skills through personal experiences, others' experiences, thinking, doing, reading, writing and improvising.

(6) Children tend to follow their teacher. He should, therefore, demonstrate them the various elements of scientific methods by self example through diverse problem-solving activities[9].

Any effective programme of science education should rest on most of the above mentioned assumptions. It is possible to clarify them still further through additional research, in different types of schools. According to Mitchell, discovery comes naturally to a vast majority of children at all ages. 'Essay in discovery' is not foreign to them. In his opinion, it is entirely the fault of the adult if the children do not show this inquisitive behaviour. Curiosity about how things work is one of the strongest drives of young children. Let us now discuss at depth what we actually mean when we talk of science and its outcomes.

SECTION B

Outcomes of science education

What is science ?

Science is an endless frontier. One, therefore, gets into difficulties when one thinks of defining science. It is viewed differently by different people. Philosophers, mathematicians, scientists, engineers, technologists, inventors, politicians, economists, sociologists, phsychologists, teachers, students, and other laymen have their own concept of science in the light of their own experience with the form, content and products of science. It is no wonder then that it is difficult to find a commonly agreed definition of science for it suffers from multiplicity of aspects. Consequently, science tends to defy its own definition. It should not be forgotten that even in the ancient past, it was the function of science to aim at 'understanding of things, contemplation of truth, essence of things'[10]. There was little difference between science and philosophy. Philosophy was regarded a life of happiness. 'Blessed is he', said Euriphides, 'who has taken knowledge of science—contemplating the ageless order of deathless Nature...how it came to be formed, its manner, its way'.. The ancients were equally curious of 'how many times the length of its legs does a flea jump'? In the words of Democritus, it is of 'greater gain to find an aetilogy than to become the king of Persia'[10].

It is comparatively easier to experience science, like life, than define it. It can be defined behaviourally as what scientists do. It is also controversial what scientists actually do because in their own endeavours, they also commit all sorts of mistakes, of course, intelligent ones at the time but, later on, considered equally foolish and silly. In fact, the term science (Scientia) is 'etymologically synonymous with knowledge' which, of course, true does not imply that all knowledge is science. The description of science as a body of systematized knowledge is also inadequate because the 'extensions of the definition, customarily and legitimately made, embrace the practices of finding out and using what becomes known, together with the human skills necessary to or acquired in the process'. 'Science thereby becomes knowledge acquired in a particular way...it becomes a human activity, an attitude and an exercise of the mind that puts us as it were in a state of familiarity with nature' (Gilbert Archey). The Columbia Encyclopedia defines Science as '...an accummulated and systematized learning in general usage restricted to natural phenomena'. 'The progress of science is marked not only by an accummulation of facts, but by the emergence of scientific method and of scientific attitude'. The former includes functional understandings or generalizations and the latter processes of science like questioning, defining problems, forming hypothesis, planning the solution, discussing, and applying knowledge etc. At the formal level, it is possible to categorize, the various processes of science into the following categories, each containing a group of problem-solving processes ;

(a) Application of generalization to new situations
(b) Collection of data
(c) Analysis of data
(d) Synthesis of data
(e) Evaluation of data[11].

It is also possible to see the problem a bit differently, that is, chronologically. It is not beyond human ingenuity to trace the historical growth of the main scientific ideas, which built up our present day civilisation, to a distant past. The lesson that emerges from this fascinating analysis is that the scientists all over the world right throughout history have built the present day body of scientific knowledge by basing it on each other's work. It is, thus, the Cumulative Nature of Science. Even Newton, a scientist of great fame, stood on the shoulders of giants like Kepler who in his turn also stood on the shoulders of his predecessors, like Copernicus and Ptolemy. The resulting body of scientific knowledge as a result of the succeeding efforts of the research workers thus tends to be both static and dynamic. To put in other words, both dogmatism and discovery are inherent at any given time in the body of scientific knowledge. To quote J.D. Bernal :

> Science is far more than total assembly of known facts, laws and theories, criticizing and often destroying as much as building. Nevertheless the whole edifice of science never stops growing. It is permanently, as we may say, under repair; but it is always in use[12].

There is an obviously educational implication underlying the above statement for the practising teachers. They should thoroughly introduce their youngsters to the fluid (provisional) nature of science by making use of relevant instructional and illustrative materials suitably adjusted to their mental development. For example, projects and their implications. They will thus learn to tolerate a certain degree of confusion or vagueness as they forward their thinking in any problematic area. Thus it explodes the popular myth that scientific knowledge under all conditions is absolutely certain.

Definitions of science

We have already mentioned that science tends to defy its own definition. It is of dual character, namely, concrete and abstract. Analysis is complete but synthesis of the analytic parts immediately becomes abstract like the definition of intelligence or electricity or motivation or the value system comprising truth, beauty and goodness. According to Herbert Dingle, science deals not only with hard stubborn facts but also with generalized ideas. Both collectors and guessors carry on the trade of science (Bancroft). Science in its forward march does not always follow a precise or even predicted path. In fact, it is the 'business of science to go wrong' (J.R. Oppenheimer). One need not at all get surprised when one is told that science reaches truth 'across a multitude of errors' (Claude Bernard) or falsehood by strictly following precise steps (J. B. Conant). This erratic act is subject to self correction; and provides facts and concepts which strengthen each other. In this context, it is the creative aspect of science (Jocob Brownski). Scientific method alone does not, strictly speaking, constitute science. 'It has to make use of a third type of statement', that is, the language of observation (Philip Frank). The highest court of appeal in science is not the individual, however high and low he may be, but the 'Book of Nature'. This is so because the principle of authority is completely discarded in the field of science. Like the proverbial five blind persons who came home to reconstruct the whole elephant, on the basis of their individual perceptions, science has several aspects : 'Science as a body of knowledge; methods and modes of inquiry; science as human endeavour, Science = technology (synonymity); science as something as mystical; science = nature (synonymity); science = scientist (synonymity); science as a manifestation of truth; science—technology relationship (related with each other or develop each other); and science—nature relationship'[13]. It is possible to place most of the definitions of science in anyone of the above mentioned categories or the various aspects of science. But still, any one of the above mentioned aspects does not define science in toto on which there is a consensus. As an interesting exercise, let us now mention below the various definitions of science encountered in literature.

(1) If one surveys the relevant literature, one comes across the following phrase like definitions of science, 'magic' tricks; health; happiness; comfort; engineering and technology; innovation, technology and engineering, a thing of the

highest glory; productive and proficient cow; economic growth; a classified common sense to deliver a knock out blow in an argument; not really phenomena but ways, explanations and speculations about phenomena; knowledge and understanding; pursuit of knowledge for its own sake; pursuit of evasive truth; topography of ignorance; mixture of fact and fiction; way of thinking or living; Inquiry : stable and fluid; puzzle solving; ordered technique as well as rationalized mythology, systematic interpretation of nature into a frame of law; study of everyday common experience and the discovery of general principles; observation, exploration, experimentation and investigating along with control and comprehension; asking appropriate questions; organized, systematized, metrical knowledge deducible from a limited number of principles; verification; forming and testing of hypotheses against observed facts; discovery of causal system; and experience in search of meaning; and thereby develop concepts that make observations coherent and logical'.

—N. Vaidya

(2) Science is not a matter of merely looking at test tubes and mixing this and that and producing things big and small. Science is ultimately a way of training the mind and the whole life's functioning according to the ways and methods of science, that is, the whole structure, social or otherwise, functioning in the spirit of science.

—J.L. Nehru

(3) Science is not technology, it is not gadgetry, it is not mysterious cult, it is not a great mechanical monster. Science is an adventure of the human spirit. It is essentially an artistic enterprise, stimulated by disciplined imagination, and based largely on faith in the reasonableness order, and beauty of the universe of which man is part.

—Warren Weaver

(4) Man, whatever else he be, is in and out of nature. Nature is orderly. To cope with nature, man wants to understand this order; to understand it by discovering the underlying rules. Once he has found a rule, he has gained control over that phase of nature-intellectual control in comprehension, and veritable physical control which culminates in the practical accomplishment of technology, medicine, and agriculture.

Science is man's rational tool to find those rules, and by finding them, it replaces notion by reason; magic by method; contention by evidence; and wishful thinking by sober appraisal. The book of rules is what we know as knowledge.

Science as a whole what it regards as truth that strip of possibilities left over after all demonstrable untruths have been trimmed away. And thus will remain a fairly broad hand of uncertainty, including the indeterminate, the unknown, indeterminable and the unknowable.

—Paul Weiss

(5) Science is a speculative enterprise . . . There is the static view of science and the dynamic. The static places in the centre of the stage the present interconnected set of principles, laws, and theories, together with the vast array of systematized information : in other words, science is a way of explaining the universe in which we live.

The dynamic view in contrast to the static regards science as an activity; thus the present state of knowledge is of importance chiefly as a basis for future operations.

Science is an interconnected series of concepts and conceptual schemes that have developed as a result of experimentation and observation and are fruitful of further experimentation and observation.

—J.B. Conant

(6) Science is a cumulative and endless series of empirical observations which result in the formation of concepts and theories; with both concepts and theories being subject to modification in the light of further empirical observation. Science is both a body of knowledge and the process of acquiring and refining knowledge.

—F. Fitzpatrick

(7) Science, like everything else that man has created, exists, of course, to gratify certain human needs and desires. The fact that it has been steadily pursued for so many centuries, that it has attracted an ever wider extent of attention, and that it is now the dominate intellectual interest of mankind, shows that it appeals to a very powerful and persistent group of appetites. It is not difficult to say what these appetites are, at least in their main division. Science is valued for its practical advantages, it is valued because it gratifies disinterested curiosity, and it is valued because it provides the contemplative imagination with objects of great aesthetic charm. This last consideration is of least importance, so far as the layman is concerned, although it is probably the most obvious, on the other hand, that the bulk of mankind values science chiefly for the practical advantages it brings with it.

This conclusion is borne out by everything we know about the origin of science. Science seems to have come into existence merely for its bearings on practical life.

—J.W.N. Sullivan

(8) Science as something existing and complete is the most objective thing known to man. But science in the making, science as an end, is as subjective and psychologically conditioned as any other branch of human endeavour—so much so that the question, what is the purpose and meaning of science ? receives quite different answers at different times and from different sorts of people.

It is, of course, universally agreed that science has to establish connections between the facts of experience of such a kind that we can predict further occurrences from those already experienced. Indeed, according to the opinion of many positivists, the commonest possible accomplishment of this task is the only end of science.

I do not believe, however, that so elementary an ideal could do much to kindle the investigators' passion from which really great achievement have risen. Behind the tireless efforts of the investigator, there lurks a stronger, more mysterious drive : it is existence and reality that one wishes to comprehend. But one shrinks from the use of these words, for one soon gets into difficulties when one has to explain what is really meant by "reality" and by "comprehend" in such a general statement.

—A. Einstein

(9) Science is the investigation and interpretation of events in the natural, physical environment and within our bodies. Probably man has always wondered about the world. Certainly, children continue to ask questions, to seek answers, and to make sense out of the 'blooming, buzzing confusion, of the world into which they are born. Science is perhaps our most important approach to understanding. It is of special importance that our children become aware of how we strive for understanding and the nature of the conceptional structures that have been built through science.

Through the use of the methods and processes of science, we have developed conceptual schemes that help us organize our knowledge of the world in which we live. The weights of various chemical elements were merely a set of numbers until Mendeleev and others arranged them in order and noticed that in their list various physical properties recurred periodically. Mendeleev built a periodic Table of the elements. This periodic Table was such a powerful conceptual properties of chemical elements that had not yet been discovered.

What should children gain from a study of science.

We answer with four goals :

1. The building of a world view that is in conformance

with the view of our world and our universe now being developed in the sciences;

2. The fostering of an understanding of the conceptual structure of science;
3. The development of skill in using some of the key processes of science; and lastly
4. The encouragement of an informed application of man, and of how science affects modern man and his society.

—W. J. Jacobson

(10) Science may be taken as an institution, as a method, as a cumulative tradition of knowledge, as a major factor in the maintenance and development of production and as one of the most powerful influences moulding beliefs and attitudes to the universe and man. This does not mean that there are as many different sciences. Science has so changed its nature over the whole range of human history that no definition could be made to fit.

More than any other human occupation, science is, by its very nature, changeable. It is also, as one of the latest achievements of humanity, changing most rapidly. Nor has it long had a separate existence. At the dawn of civilization, it was only one aspect of the work of the magician, the cook or the smith. It was not until the seventeenth century that it began to achieve an independent status; and that independence may itself be only a temporary phase. In the future, it may well be that scientific knowledge and method will so pervade all social life that science will once again have no distinct existence.

—J.D. Bernal

(11) Science...leads us to classifications and systems independent of the individual thinker, to sequences and laws admitting of no play room for individual fancy...That form of popular science which merely recites the results of investigations, which merely communicates useful knowledge, is from this standpoint bad science, or no science at all...If any such work gives a description of phenomena that appeals to his imagination rather than to his reason, then it is bad science. The first aim of any genuine work of science, however popular, ought to be the presentation of such a classification of facts that the reader's mind is irresistibly led to acknowledge a logical sequence—law which appeals to the reason before it captivates the imagination. Let us be quite sure that whenever we come across a conclusion in a scientific work which does not flow from the classification of facts, or which is not directly stated by the author to be an assumption, then we are dealing with

bad science. Good science will always be intelligible to the logically trained mind, if that mind can read and translate the language in which science is written.

—Karl Pearson

(12) The edifice of science not only requires material, but also a plan...without the material, the plan alone is but a castle in the air—mere possibility; whilst the material without a plan is but useless matter . . . In the work of science, the artisan, architect, and creator are very often one and the same individuals; but sometimes, as in other walks of life, there is a difference between them; sometimes the plan is preconceived, sometimes it follows the preparation and accumulation of the raw material. Free access to the edifice of science is not only allowed to those who devised the plan, worked out the detailed drawings, prepared the materials, or piled up the brickwork, but also to all those who are desirous of making a close acquaintance with the plan, and wish to avoid dwelling in the vaults or in the garrets where the useless lumber is stored.

Knowing how contented, free, and joyful is life in the realm of science, one fervently wishes that many would enter its portals.

—Dmitri Mendeleev

(13) The aim of science teaching is not the acquisition of information and a few skills but to attain the understanding of the relationship which connects the answer to the problem.

—W. Pauli

(14) In the literal sense, science means the pursuit of knowledge but it has a wider connotation for our purpose, and can be said to mean a knowledge of nature in the widest possible form. This includes nature study physics, astronomy, meteorology and much more. It is equally important to look beyond mere precise definition and see what science includes, and the following are of fundamental importance to the approach to his subject :

1. Direct and indirect observations
2. Scientific inquiry-asking questions
3. The drawing of inference from evidence
4. Recording observations
5. Developing ways and means to find answers
6. Classification and checking evidence

Science in fact is more than a subject, it is a method of acquiring knowledge and of necessity the approach must be correct.

—Cedric Griggs

(15) Science Processes involve :

1. Accurate and Precise Description. Essential to scientific procedures is the establishment of common understandings. Each word of science must call to mind a specific item or concept. It is for this reason that so much new and specialized vocabulary must be learned by the neophyte in science.
2. Classification. Because of the vast numbers of individual phenomena, it is difficult to reach conclusions or generalizations about them when they are considered individually. Thus, some kind of grouping or classifying is a first step, and the basis upon which groups are established, the nature of the classification system that is built, becomes an important aspect of science. Not only is it important to understand that individual items or phenomena are grouped together in given ways; it is equally necessary that the scientist understand why one way of classifying has been chosen rather than another.
3. Repetition. If an event is to have scientific significance, there must be the possibility of its being made to reoccur. If the conditions necessary for repetion can be established, the scientist can repeat an event and determine whether he has been accurate in describing it. Further, if an event can be made to reoccur, there is a possibility that it can be controlled.
4. Consensus. When a repeateable event is reported, other scientist can try to duplicate it. If a group of men try the same thing and all come to the same conclusions, it is probable (though not necessarily certain) that the event really has taken place in the manner reported.
5. Experimentation. By imposing variation in the conditions controlling an event, scientists can obtain new and often valuable information. As he studies the results of his verifications, he records his findings and often learns entirely new information about the subject of his studies.
6. Measurements. Measurement is a particular kind of description. Through the use of numbers and mathematical relationships, observed phenomena often can be described specifically, and duplication by other

> scientists can be facilitated. Measurement makes description more objective.
>
> —Percy Bridgman

Critical appraisal

Let us reflect over the above mentioned sixteen varied definitions of science[14]. It becomes quite evident on reflection that it has proved a difficult exercise to search for a single omnibus definition of science either in a single key statement or a series of such statements. It appears to share its fate with the definition of intelligence, a suspect entity now, after the psychologists have worked too much to dig it out. In a science and technology weighted society, it appears to be as vast as life. In this wide framework, it is not possible to define science because it is not an isolated subject or even subjects having a well defined face, say, like that of a chemical crystal. Cumulatively speaking, or right throughout its historical development, it did have neither a beginning nor is it likely to have a terminal point. It tends to become or resemble a philosophical issue in which as the first requisite, the scientists have to define their terms, as clearly as possible, like programmers for the benefit of philosophers. There are several aspects of it which intermingle with each other indistinguishably. Like historical dates places and figures, science is not merely a body of hard and stubborn facts. Both then devalue history and science conceptually. It is a mixture of facts and unfacts which necessarily and invariably are seen selectively. It is also not merely a body of concepts and principles alone because there is no sanctity about the fundamental ideas of science. The more they are exploded, better is the resulting scientific body of knowledge. For example, the (undivisible) a-tom of the Greek philospher Democritus. Further, little is known about the psychological formation of the basic notions in science, for example, concept formation, problem solving and skills etc. Facts, concepts and skills take the scientists to the frontiers of knowledge but the latter are pushed back only by the scientific methodology. It is also not commonsense, classified or otherwise, because it can conflict with tested knowledge. The Theory of Relativity as propounded by Einstein goes interestingly far enough in contradicting almost all our common sense ideas held about this world :

> There was a young girl called Miss Bright who could travel much faster than light. She departed one day in an Einsteinian way, and came back on the previous night[15].

Secondly, it will be a miserly and poorly appreciation of science if it is identified with up-to-dateness, modernity, progress, health, happiness, leisure, Beecham's powder, engineering, technology and even economic development as now-a-days, strictly speaking, conceived in the developing countries, In the micro-world, decision making elements in scientific methods, that is, the nature of inductive inference, has become questionable because of the intrusion of probability and chance. This has resulted in not getting a clear verdict either way on the truthfulness or falsehood of a particular hypothesis under test especially when it happens to be partly true meaning 'thereby that it would become more nearly so with the adjunction of further hypotheses'. To put in other words, it means that the young bride of the twentieth century can only talk about the chances of her marriage on a particular day in contrast to her counterpart who could announce the same with absolute certainty in the nineteenth century. In addition, it is also necessary to translate the language of abstract principles into the language of observation using linguistic analysis according to Philip Frank. What then exactly is the role of science ? Its role or function is providing an intellectually and aesthetically satisfying experience in the pursuit of knowledge; and for its practitioner, its spirit is free enquiry—no sacred cow to worry about both in method and content or product and process when applied to any problem situation; and where the principle of authority is fully rejected. Against this background, it would not be out of place to define science somewhat as follows :

Attempting a definition of science

Science is a great human enterprise : not only endless and faceless but also stable and fluid. It is less complicated than an erratic lady who cannot correlate her varied behaviours : self-accumulating, self-growing, self-pervading, self-accelerating and self-correcting enterprise which originated in immense curiosity of man since time immemorial. It attempts to provide an objective body of knowedge, through objective as well as subjective procedures, which is as objective as the prevailing conditions make it, that is, do not challenge it. In every generation, it operates in a certain frame of reference which yields to another imperceptibly, gradually or even violently sometimes in the light of new observations and interpretations. It thus wheels on dogmatism, dynamism and discovery at the same time. Open mindedness, arousal and maintenance of curiosity, questioning the basis of all things (including assumptions), collection of data, demand for verification and proof, respect for mathematical arguments and logical proofs including statistical reasoning, suspended judgement, acceptance of warranted conclusions and willingness to change one's opinion in the light of new evidence are the ferments which characterize the scientific enterprise.

What is science then ? It is puzzle-solving or problem-solving or an exercise at abstracting and reabstracting knowledge and skills with a view to approach and understand the unknown. This is done through diverse ways which embrace in one form or another the so-called steps in scientific methods : observavation, problem survey, formulating and reformulating problems, setting up hypothesis and control experiments, suggesting plausible explanations on the basis of evidence collected, finding exceptions, developing, using and refining concepts, mathematization of arguments and their application to dig new knowledge, finding principles and laws, and lastly developing relevent theories which influence our global out-look.

Interestingly enough, it is an international activity least confined to national frontiers. Incidentally, accidentally and intentionally (through research and development followed by the commercial exploitation of scientific discoveries), it strengthens national economies, creates new resources, accelerates employment and attempts to build global outlook on problems which effect man and his society. At the same time, it is double-edged, it can kill as well as save many !

Limitations of science

Science is an evergrowing body of provisional knowledge. All its propositions and concepts are provisional until confirmed conclusively. It must not be forgotten, despite overwhelming achievements of science, that science is not the sole method of reliable and valid thinking. At present, it only investigates limited aspects of our environment. It only attempts to answer those problems which can be posed in their solvable forms. What happens after death ? is an impossible problem for the scientist to solve. But at the same time, he will be less of a friend to the advancement of science directly or indirectly if he refuses to participate effectively in the definition of death. Or he refuses to study aging because he cannot prevent death. It neither makes judgement on philosophical values nor investigates them. It can explain how things happen but cannot answer why things happen. For example, science can explain successfully how water boils in a kettle (efficient cause) but cannot tell why after all kettle was put on the stove (final cause). It amounts to saying that science only investigates efficient rather than final cause[16] (Eric Ashby).

Secondly, we have pointed out that science has several aspects or facets : systematized knowledge, inquiry (stable and fluid), human endeavour or adventure, manifestation as well as pursuit of truth, strictly a study of nature rather than nature study, magic and mysticism when not understood, science synonymous with scientist and his activities, science equated with engineering, technology and economic growth, and the age old science-nature relationship. In all these multi-aspects of science, subtle issues are involved. Naturally, it is of great consequence to the real nature and spirit of science to reflect frequently over the current issues in the area of philosophy of science in our day to day science teaching. Failure to do this will result in poor appreciation of the role of science in general. These incomplete discussions will go a long way in illumining the very bases of science, that is, in clarifying concretely the limitations of science. Michael J. Daley has gone to the extent of suggesting a test or instrument which can measure the various responses to a series of statements about the misconceptions of science (other similar statements can be added). It is quite possible to choose quite interesting statement for this instrument which provoke thought and discussion. To quote Michael J. Daley :

Key

(i) Impossible. Science is limited (1)
(ii) Possible solution with research (2)

(iii) Least possible for solution with research (3)
(iv) No opinion (4)
(v) Has been accomplished (5).

Questionnaire (use the above key to evaluate critically the following statements given below :

(a) Man will land on the moon's surface.
(b) Man will be able to communicate with other forms of life.
(c) Man will conquer all diseases.
(d) Detection of birth defects.
(e) Slowing down of aging process.
(f) Artificial control of weather.
(g) Artificial control of life functions.
(h) Total cure in mental health.
(i) Solve air pollution problems.
(j) Find cure for cancer (all types)
(k) Present world food shortage.
(l) Prevention of human error.
(m) Reaching absolute zero.
(n) Developing cities in the oceans.
(o) Stopping of world conflicts.
(p) Preventing drug addiction by education.
(q) Prevent birth defects.
(r) Be able to transplant most body organs to another individual[17].

It is possible to choose additional suitable controversial statements which deal with 'unfinished business' of science, technology, education and society. Examples are synthesizing a human hand or a green leaf, transport of human and animal population to moon and mars, the blades that never blunt, mini foods for children and adults, eradication of poverty, educational aids which will make learning permanent, war to end wars, the belief in master race and so on. Critical discussion on the above-mentioned problems will help students evaluate the current status of scientific knowledge as well as help them see the various limitations of the different branches of scientific knowledge against the back drop of the explosion of knowledge. This after all is an educative exercise in the basic education of citizens and scientists.

Objectives of science education

It is important to seek the continual clarifications on the various objectives of science education for establishing worthwhile goals of science education against the backdrop of the real nature of scientific enterprise. We have discussed a part of this problem at depth elsewhere (See *The Impact Science Teaching*). Here it will suffice to say that the various objectives of science education are : functional understandings (scientific vocabulary, facts, concepts and principles, their applications also included); scientific skills (general, concrete, abstract social etc.); scientific attitudes, scientific interests; and appreciations. Due to the clerical system of education, science is still regarded as a lump of content to be taught and learnt, largely speaking, for examination purposes. Unfortunately reform in science education is only seen in downgrading or upgrading content at various grade levels. This naturally results in the distorted image of science as a great intellectual as well as human adventure among our young boys and girls still at school. The malady goes still further when we find scientific, illiteracy among our scientific literates, particularly science teachers. To put in other words, it amounts to saying that our young boys and girls are being miseducated in science education on a large scale for they continue to be deprived of the acquisition of scientific attitudes, interests and appreciations. Here, we have to make the following comments on scientific attitudes and appreciations. Attitudes influence our behaviour. They are 'largely learned and are difficult to distinguish from such effective attributes of personality as interests, appreciations, likes, dislikes, opinions, values, ideals and character traits'. There is an emotional element in them which varies in intensity as well as in generality among different persons. Attitudes held by the individuals may be simple or complex, stable or unstable, temporary or permanent and superficial or fundamental. Judgements based upon insufficient or faulty facts are likely to yield wrong results and thereby develop biased attitudes. Finding answers to problems through direct observation, adequate experimentation, argumentation on facts, verification and testing of knowledge are some of the initial manifestations of scientific attitudes. Especially for young children, these varied aspects of scientific attitudes need further to be concretized in terms of well-planned teaching learning situations and meaningful activities. This built-in intention in science teaching is more likely to result in the gradual growth of scientific temper among our children. Some characteristics of this scientific temper are : open mindedness, arousal and maintenance of curiosity, judgement based upon scientific facts alone, willingness to test and verify conclusions, suspended judgement, belief in cause and effect relationship, honest reporting, rejection of the principle of authority, and more faith in the books, written by specialists in their respective fields. Paul B. Diederich mentions the following twenty components of scientific attitude which sample well the definition of scientific attitudes :

1. Scepticism.
2. Faith in the possibility of solving problems.
3. Desire for experimental verification.
4. Precision.
5. A liking for new things.
6. Willingness to change opinions.
7. Humility.
8. Loyalty to truth.
9. An objective attitude.
10. Aversion to superstition.
11. Liking for scientific explanations.
12. Desire for completeness of knowledge
13. Suspended judgement.
14. Distinguishing between hypothesis and solution.
15. Awareness of assumptions.
16. Judgement of what is of fundamental and general significance.
17. Respect for theoretical structures.
18. Respect for quantification.
19. Acceptance of probabilities.
20. Acceptance of warranted generalizations[18].

The above mentioned characteristics are not only that of scientific attitudes but also that of rationality as well. Science would suffer where these are abused either by the politicians or by the priests of science holding power. Science teaches its lessons to those who always seek success by hook or by crook. At times, negative findings are equally revealing. They tell us what not to expect under certain conditions (Micheson Morley experiment which exploded the myth of ether). Results could be disastrous when politicians interfere with the firm observations and conclusions of the scientists. Consider one of Lysenko's recent claims :

> If you have a big cow, of a breed that produces milk with a poor fat content and a small bull of a breed giving milk rich in content and if you mate the two—then you can fix whether the calf takes after the mother or the father or by the food that you give to the mother. It is the cow's food, in his view, not the genetic factors, that is, the most important for the future of the breed.
>
> "It is possible", he claims, "to direct the development of the embryo, according to the experimenter's desire, either towards the paternal fat milk breed of low fat content or everything depends here on the intensiveness of the feedings of the cows".
>
> ...Khruschev took to task the scientists who objected to this particular Lysenko method. He was not against arguments in science; he said "they must not be stifled". But, he added in an aside about the anti-Lysenko school, "if we do not notice where barren scientists abuse real scientists who enrich science and practice, this will damage our common interests......if other did not get any results, it does not mean that the theory is wrong[19].

Attitudes also appear to develop in stages : willingness to respond; satisfaction in response; and acceptance, preference, commitment and conceptualization of a value. It is at the last stage only that the learner sees formally his firmly held opinion or value in relation to other values, possibly, equally competing. Lastly, a science teacher has to be quite careful in his day to day teaching. He has himself to demonstrate the various aspects or components of scientific attitudes in his behaviour towards children. If he does not, students, in essence, lose the opportunity of acquiring scientific attitude in their formative years. Acquisition of facts is necessary but not sufficient for a scientific outlook which relates science to all other areas of human experience and knowledge.

Scientific Appreciations

Let us now refer to scientific appreciations. The development of scientific appreciation is something akin to appreciation in art, music and literature. William Blake's stricture against Newton, in this connection needs mention : "......for replacing the elephant by a point of mass 'm' and "denying to man the richness of common experience typifies what is contradictory and vulnerable in our present civilization." "For this reason alone, it is essential to consider how we stand now". It is encouraging to note that in the new curricular programmes being developed abroad, attempt is being made to 'impart an intuition for each subject, to enable students to guess what ought to be true even before they can demonstrate it'. This intuition is also quite akin to aesthetic appreciation. Professor Zacharias, a well known scientist, speaks of 'building a cathedril of the mind'. He is not alone. Even the mathematicians intend to instill a sense of elegance in their subject. In other words, it means that an intentional effort is being made to teach most of the school subjects, for example, language and history, not only as a body of knowledge but also as an art. Scientists of all races and of all lands have disclosed us the mysteries of nature. Our efforts should not therefore remain confined strictly to the teaching of understandings alone because the accompanying element of admiration, emotion and intellectual pleasure cannot be altogether easily discarded. These elements form a part and parcel of the history of science which at present is difficult to communicate in meangingful terms : "The intelligence which education is calculated to develop will not grow when uprooted from the background of feeling from which it spring" (Wheeler and Perkins). The scientific content in their opinion needs to be developed in an evolutionary manner which will impart historical sense. The basic aim here is not to teach much of content to the students but to give them a 'feel of science'. Case study method (or history of science cases) in science teaching is the case in point. So historical approach to science teaching not only enlivens day to day classroom teaching but also dramatizes the way the incomplete house of science is built—piece by piece, brick on brick, and a scientist succeeding to a scientist. One intuitively acquires a feeling for the growth of science and cares less for the fact to be rememebred for the examination. When approach is suitably bent, even current problems can be discussed through the use of research papers. The same historical questions are asked but answers obtained to them change both in time and space. Consider the following set of sample questions used by Howard B. Baumel and J. Joel Berger with their students on Teaching from Research papers :

1. What problem was the scientist studying ?
2. What information did the scientist have at hand when he investigated the problem ?
3. What hypotheses did the scientist probably have at hand as he planned his investigation ?
4. What was the outcome of the experiments : observationally and in relation to the objectives ?
5. What conclusion was reached ?
6. Is the conclusion justified ?
7. What simple experiment could you plan to verify the conclusion ?
8. What have you used in the plan that was not available to the scientist[20] ?

It fires the imagination of youngsters when they are told that Lavoisier, whose work brought about revolution in chemistry in the eighteenth century recorded barometric readings for thirty years in different parts of France for identifying factors which control weather. He did not have the physical constitution of an Ox. Still, he had unlimited capacity for intelligent and hard work. In a similar way vein, Einstein spoke of the contributions of Planck to science :

> In the temple of science are many mansions, and various indeed are they that dwell therein and the motives that have led them thither. Many take to science out of joyful sense of superior intellectual power; science is their own special sport to which they look for vivid experience and the satisfaction of ambition; many others are to be found in the temple who have offered the products of their brains on this altar for purely utilitarian purposes. Were the angel of the Lord to come and drive all the people belonging to these two categories out of the temple, it would be notice-

> ably emptier, but there would still be some men, of both present and past times, left inside. Our Planck is one of them, and that is why we love him[21].

Understandings and their applications enrich appreciations but the latter cannot be taught like them. Appreciation bereft of understanding is meaningless. Appreciation resists evaluation because it constitutes an intangible outcome of science instruction. Illustrations, narrations, dramatizations, mock ups, field trips and other activities at the science corner are some of the factors which will create sufficient experential background. This can be, later on, exploited to develop scientific appreciation because the requisite material has been first created before it has been moulded. The above mentioned outcomes of science education are, in fact, broad categories which need not be considered independent of each other. They are not to be regarded as the chips of different blocks but different chips of the same block. In this context, they need further specific statements to be made, not only about the subject matter in a given area of science but also corresponding learning experiences which will help to achieve what has been aimed at in terms of objectives and behaviour changes (also applicable to a topic or unit of instruction) by making use of, as much as possible, of the community resources. This cuts down incidentally the cost of imparting science education as well.

Concluding statement

Lastly, the depressing and despicable atmosphere in our classroom must change for the better, for drabness, dullness and drudgery in an educational medium have been too long with us in this country. It should not be forgotten that the objectives of scientific education are not defeated even when there is little emphasis on syllabus, textbook and examination considered sacred like cows in our country. There is always necessity of selection criteria for selecting the various outcomes of science teaching which in our opinion are :

1. The specific outcomes should stem from general outcomes which in their turn must be consistent with the aims and objectives of secondary education.
2. The specific outcomes should not only be worded in

an unambiguous manner but also be quite practicable for the classroom teacher.

3. The specific outcomes should be psychologically sound.
4. The specific outcomes should be so worded as to be possible of attainment under the existing conditions and that so to a measurable degree.
5. The specific outcomes when developed should take into account the mentality of children, their socio-economic backgounds, and aspirations etc.
6. Lastly, the statement of specific activities should suggest directly or by clear implication the relationship between classroom activity and the changes expected in human behaviour.

3. The Nature of Thinking and Problem-Solving

(i) One of the most remarkable characteristics of the age in which we live, is its desire and tendency to connect itself organically with preceding ages—to ascertain how the state of things that now is came to be what it is. And the clearly comes into view the vast and varied debt which the world of today owes to that foreworld in which man by skill, valour, and well-directed strength first replenished and subdued the earth. Our pre-historic fathers may have been savages, but they were clever and observant ones. They founded agriculture, by the discovery and development of seeds whose origin is now unknown. They tamed and harnessed their animal antagonists, and sent them down to us as ministers, instead of rivals in the fight for life. Later on, when the claims of luxury added themselves to those of necessity, we find the same spirit of invention at work. We have no historic account of the first brewer, but we glean from history that his art was practised, and its produce relished, more than two thousand years ago. Theophrastus, who was born nearly four hundred years before Christ, described beer as the wine of barely. It is extremely difficult to preserve beer in a hot country, still Egypt was the land in which it was first brewed, the desire of man to quench his thirst with this exhilarating beverage overcoming all the obstacles which a hot climate threw in the way of its manufacture.

Our remote ancestors had also learned by experience that wine maketh glad the heart of man. Noah, we are informed planted a vineyard, drank of the wine, and experienced the consequences. But, though wine and bear possess so old a history, a very few years ago no man knew the secret of their formation. Indeed, it might be said that until the present year (1876), no thorough and scientific account was ever given of the agencies which come into play in the manufacture of beer or the conditions necessary to its health, and of the maladies and vicissitudes to which it is subject. Hitherto, the art and practice of the brewer have resembled those of the physician, both being founded on empirical observation. By this is meant the observation of facts, apart from the principles which explain them, and which give the mind an intelligent mastery over them. The brewer learnt from long experience the conditions, not the reasons, of success. But he had to contend, and has still to contend, against unexplained perplexities. Over and over again, his care has been rendered nugatory ; his beer has fallen into acidity or rottenness, and disastrous losses have been sustained, of which he has been unable to assign the cause. It is the hidden enemies against which the physician and the brewer have hitherto contended, that recent researches are dragging into the light of day, thus preparing the way for their final extermination.

—John Tyndall

(ii) Men sail a boundless and bottomless sea, there is neither harbour for shelter, nor floor for anchorage, neither starting place nor appointed destination. The enterprise is to keep afloat on an even keel; the sea is both friend and enemy : and the seamanship consists in using the resources of a traditional manner of behaviour in order to make a friend of every hostile occasion.

—Michael Oakeshett

Introduction

It is not really known when science originated in our march to our present day civilisation. The reason for this is that during the entire period of unrecorded history, science as such did not exist but at the same time, it undistinguishably formed part of the entire community life which, largely speaking, revolved round the problems of food, shelter, clothing, aggression, safety and campfire (entertainment). The inclement nature and the harsh realities of life compelled the ancients to adjust but they did not stop at that. Intense curiosity drove them to appreciate the heavenly glory (sun, moon and stars) physical phenomena (day and night formation, lightning, rain, and weather as agriculture developed), and plant and animal life (animals, birds, bees and jungles). Over several centuries, the primitive men succeeded to develop distinct material basis of life (implements, tools, clothing, fire cookery and animal lore); social basis of life (communication : gestures, language and symbolism, food gathering and hunting leading to division of labour, totemism, magic, myths and rituals); and intellectual basis of life which helped them to cope with their day to day problems as well as gain satisfaction of curiosity (astrology, mechanism and elementary mathematics, physical cure and witchraft). As their extensive physical encounters with their immediate environment increased, they began to understand and control their environment gradually. They thus tried hard to find sense in their environment by suggesting suitable explanations which look ridiculous to us today. This is, however, deceptive. It is a mistaken notion that we would have been more wise had we found ourselves in their position, time and place when not only answers but also the sort of questions to put to nature hardly existed. Still, they made highly interesting observations and inferences. For example, the flame goes up because it is in the nature of flame to go up. It is precisely for the same reason alone that a pebble thrown in the air falls down to the ground. To boil water, they put red hot stones into it rather than heat it straight on fire. They had to discover everything, mostly empirically. Their growing experience led to the 'coordination and standardization' of common sense knowledge and industry. About 4500 years ago, the Babylonian rulers issued under royal authority fiscial units of length, weight and capacity : finger (1.65 cms), and purveyor's cord (3600 (fingers) ; grain (.046 grammes) and shelkel (8.416 grammes) and talent (30.5 kilogrammes) ; and medium of exchange (barley, copper, silver and gold).

Interestingly enough, they also speculated over the shape of earth which they declared to be flat. It had an edge beyond which nobody could dare to go for the fear of loss of life. There were some exceptional speculative men here and there who thought otherwise, for example, Pythagoreans. They looked at this problem mathematically and predicted that earth had to be spherical rather than flat. Nobody trusted them or took them seriously because this prediction contradicted their first hand observation. The Buddhist philosophy went still ahead not only by declaring faith in atomicity of matter but at extending this notion to time: Everything according to this theory, exists but for a moment, and is in the next moment replaced by a facsimile of itself, very much as in a kinematescopic view'. 'The thing is nothing but a series of such momentary existences' The Indians also developed a system of notations out of which was developed the scheme of numerals currently in use. Plato felt sorry for one of his pupils who, bewildered by abstract mathematics, asked his master one day about the utility of abstract equations. Plato in anger gave him a coin and asked him to leave the academy at once. According to Greek thought, the highest form of life to live on this earth was that of contemplation. The practical life, they thought, firmly, degenerates humans. Plato made a significant contribution to scientific method by elucidating precise relations between 'fact and theory ; and experiment and hypotheses'. He elaborated how to declare whether a given problem is solvable or not solvable. He advocated an approach in which a problem is assumed to be solved by stating firmly a given hypothesis and then making deductions regressively. A problem is thus solved backward, which makes it easy to test deductive statements in it for truth or falsehood. In his Republic, Plato gave an ideal pattern of discovery and explanation resting on reasons in search of hypothesis to his serious readers :

> ...but as genuine hypotheses, that is to say, as stepping-stones and impulses, whereby it may force its way upto something that is not hypothetical, and arrive at the first principle of everything, and seize it in its grasp ; which done it turns round, and takes hold of that which takes hold of this first principle, till at last it comes down to a conclusion, calling in the aid of no sensible object whatever, but simply employing abstract, self-subsisting ideas, and terminating in the same[1].

Socrates and Plato were deductive thinkers. Aristotle was not, because he made an extensive inquiry into the science of reason as distinct from art of reason. He formulated Laws of Thought (Law of Identity, Law of Contradiction, and Law of the Excluded Middle) which must be invariably used to obtain logical knowledge. To test the validity of arguments, he even gave subject-predicate type statements popularly called syllogisms. (All men are mortal : Ram is a man : and therefore, Ram is mortal). He had strong biological interests which coloured his philosphical outlook. His powers of observation were remarkable. He described accurately at depth the reproductive system of 'smooth shark' which was considered nonsense until the nineteenth century. He advocated the role of observation in scientific methods. Biological studies held sway over him. He developed the doctrine of four causes which he applied successfully to interpret the physical world : the material cause (basic stuff or stone for the sculptor) : the formal cause (basic law directing the phenomena) : the efficient cause (motivating factor which triggers off the action or phenomenon) : and the final cause (final aim of the phenomenon).

Logical argumentation with little reference to basic experience reached its peak of misuse in the middle ages right upto the times of Roger Bacon, Renaissance and Galelio. Scholars of these times engaged themselves with interesting problems, for example, 'How many angels could dance on the point of a needle' ? They threw a monk out of the window who suggested to count physically the teeth of a donkey rather than consult the works of Aristotle on this problem. No observation could be made and confirmed which had not been earlier observed and described by Aristotle. Due to individual greatness, Aristotle may have halted progress for several centuries. This is not his fault but Bertrand Russell appears to have indicted Aristotle and his followers severely for the same :

> To modern educated people, it seems matters of fact have to be ascertained by observation, not by consulting ancient authorities. But this is an entirely modern conception, which hardly existed before the seventeenth century. Aristotle maintained that women have fewer teeth than men, although he was twice married, it never occurred to him to verify the statements by examining his wives' mouths... Nevertheless classical dons, who have never observed any animal except the cat and dog continue to praise Aristotle for his fidelity to observation[2]

It was not easy to break the shackles of authority. The writings of Burno were not only suppressed but also he was 'burnt at the stakes' in 1600. Francis Bacon rang the death knell of those tendencies in thinking which had made experimental philosophy infertile. He advocated the inadequacy of logic in isolation in the discovery of truth : 'The subtlety of nature is greater many times over than the subtlety of argument'. He emphasized the role of observation and experimentation in the solution of scientific problems. He thus concluded that the approach to the discovery of truth was through induction. He ruled out the role of blind experience in the discovery of truth for then the knowledge hardly advanced a bit more than the use of mechanical rules and procedures. He further detailed at depth the four principal factors which affected adversely the human judgement : the idols of the theatre (the inherent vagueness of the language in the advancement of scientific knowledge including emotive elements) : the idols of the market place (to look at things in a given social or customarily way) ; the idols of the tribe (inclination to see nature into the human mould): and the idols of the cave (personal prejudices, perceptions and preconceptions). He thus hit very badly at those speculative philosphers who solved problems logically without reference to experience. Thus dawned the age of experimental philosophy in which John Kepler, Galelio, William Harvey, Lavoisier and Newton coluld solve problems experimentally in a comparatively much freer atmosphere. It should not be lost sight of that they did not discard logic, authority and experience but used them intelligently as a source of new hypotheses and insight rather than true knowledge, and always emphasized empirical observation and proof even when the so called knowledge was self-evident. Lastly, Bacon considered the role of hypothesis prejudicial in attaining complete objectivity. This is not necessarily true, for the investigator of truth cannot look at things at random at the cost of being 'collector of odds and ends'. His observation is generally selective without any loss of sensitivity to the exceptional facts. We should not despise deductive knowledge, and at the same time, we should not be led far away by the ghost of induction in the advancement of scientific knowledge. Absolute superiority of one method at the cost of the other method led to the development of Phrenology by Gall which flourished for about one hundred years. Gall, a great anatomist of his times, could easily check his faulty premises. At the advanced stage, Albert Einstein specifically hinted at the limitations of induction :

> There is no inductive method that could lead to the fundamental concepts of physics. Failure to understand this fact constitutes the basic philosophical error of so many investigators of the nineteenth century—We now realize with special clarity how much in error are those theorists who blieve that theory comes inductively from experience[3].

Rene Descartes (1596-1650) also speculated on the basis of scientific method and elucidated four basic principles of method. Superficially, they appear to be of precautionary type and relate to judging the truth of each and every part of the solution ; proceeding from simple to complex step ; dividing of difficulty into as many parts as possible : and preparing of exhaustive 'enumerations and reviews'. In pursuit of rational certainty, he went on rejecting a series of propositions and concluded : 'I think therefore I am'. On reversing this process called Cartesian Doubt, he built his own theory of knowledge from this single atomistic proposition. It was now left to J.S. Mill (1806-1873) who in his work entitled : 'A System of Logic' developed laboriously the five basic canons which led to the identification of causes and effects. He believed firmly that the aim of science was to discover causes, for only they enlightened us in regard to sequences in nature. Like Bacon, he was a great advocate of induction and refused to assign any role to hypotheses in the development of scientific knowledge. These basic five canons were (1) method of agreement, (2) method of difference, (3) joint method of agreement and disagreement (4) method of residue and (5) method of concomitant variation. On further analysis, all these five canons are reduced to one, that is, change one factor at a time. It is possible to clarify one's knowledge and place it on secure logical grounds with the assistance of these cannons. In advanced stages of research, these can be used to generate hypotheses. For example, chemists calculated 35.5 as the atomic weight of chlorine which did not make any sense. The problem was solved when it became known that chlorine has another isotope. Their utility is now restricted, for we no longer believe in straight cause and effect relationship. There are many causes for a given phenomenon which are now a matter of probability rather than certainty. Statistical developments and multivariate analysis have entered into modern science. They are, however, still useful in deriving a large number of hypotheses which could be reduced to a limited number by logical empirical testing. It should not be forgotten that testing of each and every hypotheses costs labour as well as money.

Armchair experimentation helps. One is able to see the given problem from as many different facets as conceivably possible. Empirically, one can screen and select a few hypotheses for intensive testing. Significant human knowledge develops when the basic premises turn out to be true. Charles Darwin (1809-1882) set the pace by combining both the inductive and deductive methods in discovering new scientific facts, concepts and insights. This is what the present day modern scientist does. To put in other words, it means that the uses both inductive and deductive methods generously to full advantage in the solution of his problems. He does not at all hesitate to start the solution of problems from observation to hypotheses, that is, proceeding inductively, and then from hypotheses to observations, that is, proceeding deductively. In the process, he does not remain unaware of the implications of his tentative conclusions so far as the validity of argument with accepted knowledge is concerned, challenge to the accepted body of knowledge also not excluded[4].

THINKING AND PROBLEM-SOLVING

Thinking

The development of sound thinking in the school child is the acid test of any first class instruction. Whether attainable or not, this aim naturally ranks quite high with science teachers because they usually do show concern and regard for right concept formation, efficient and improved thinking, problem-solving, creative and critical thinking. This is true even when both psychologists and science teachers know very little about mysteries underlying thinking—which had produced tremendous knowledge for all of us. It is true that thinking is present in all of us to a certain degree but it reaches the level of original invention and discovery only in very few of us. This is why the information-mongers as well as the book-worms cannot go very far in their advanced thinking in spite of their best and persistent efforts. For these reasons, it is very pertinent to examine a few definitions of thinking or what is thinking considered to be by the philosophers and psychologists from considerations relevant to science teaching and, more particularly, problem-solving. The various views on it are mentioned below.

Philosophers and logicians have studied 'Thinking' in terms of its product and have thus developed their laws of thought : law of Identity, law of contradiction and law of excluded middle etc. In a general sense, this term may refer to 'guessing, imagining, opening, remembering, reflecting and searching for conclusion', etc. And in a restricted psychological sense, it may refer to 'percepts, images, vocal sounds, feelings and ideas' etc. Occassionally, it has also been elucidated in terms of 'mind, consciousness and judgement'. Symmond lists nineteen types of thinking such as learning meaning, stating relationship, defining and generalising etc. Humphrey equates it with problem solving, for Burt and his students a hierarchy of thinking abilities comprising relation, association, perception and sensation etc. Gestalt psychologists emphasize the perceptual and problem-solving aspect ; Bartlet considers it a high level skill in which 'symbols, words, numbers, shapes, colours and tones supplement and may take the place of bodily movements'. Peel mentions and distinguishes among four kinds of thinking (thematic, explanatory, productive and integrative) and adds that "Free association, remembering, reverie, fanciful association, punning, solving crossword clues are also other acts of thought that do not fall into these categories". Lastly, Russell develops his own schemata starting with stimulus patterns internal or external through materials of thinking (percepts, images, memories and concepts), processes in thinking (perceptual thinking, associative thinking, problem-solving and creative thinking etc) to products or conclusions. He implies thereby that abilities in thinking techniques, habits and devices etc. can be learned. From above, it appears that it is difficult to define thinking and even when defined, its explanatory terms themselves become suspect and consequently need further explantation[5].

Here, a valuable suggestion has been made by Hearnshaw in 'Recent Studies in the Psychology of Thinking', which if followed makes the investigation of 'thinking a profitable enterprise'. Thinking then ceases to be a 'ghost' like activity for the purpose of analysis. According to him, thinking should be regarded as a skill (or group of skills) which is organization. This point of view is quite consistent with Piaget's genetic findings... 'the evidence pointing to the motor accompaniments of thought and the results of perceptual studies emphasizing the dynamic nature of perception and the acquired character of all but the simplest structures'. With the passage of time, this skill becomes quite complex and is characterised by 'flexibility, transfer, generalization and accurate discrimination processes' which ultimately result in the development of highly abstract conceptual systems, conceptual system of high order and generality. With this restriction, the attack on the problem of thinking becomes possible. It is then not very difficult to investigate the process of generalization and discrimination empirically.

Productive thinking

In his book, Max Wertheimer develops the concept of 'Productive Thinking' and clearly distinguishes between structural and non-structural solutions. As a first step for the possible understanding of the process of thinking and the various outside variables that influence it, he advises teachers to develop inventories of human thought processes—qualitative approach in contrast to mathematical approach like factor analysis. His definition of thinking needs to be quoted here (because it seems to the writer to contain clearly the germs of problem-solving which we will discuss later in the next section):

> Thinking consists of envisaging, realizing structural features and structural requirements, proceeding in accordance with and determined by these requirements, thereby changing the situation in the direction of structural improvement, which involves.
>
> That gaps, trouble regions, disturbances, superficialities, etc. be viewed and dealt with structurally; that inner structural relations—fitting or not fitting—be sought among such disturbances and the given situation as a whole and among its parts[6].

Further, he emphasizes the active role on the part of the problem solver in the thinking process. He is thus sure of an unbroken and undisturbed adventurous and pleasant Gestalt journey. In productive thinking, there is an underlying active process of formulation and reformulation of the problem.[6]

Problem-solving

It refers to the application part of one of the outcomes of science education : functional understandings. Reasoning is an essential part of problem solving which itself is regarded as a complex factor comprising induction, deduction and restrictive or general reasoning. We have avoided various controversies on it (reasoning) by including it in problem-solving. The various views on problem-solving are mentioned below. It may be pointed out, however, that the educational research on problem-solving itself has so far been very little.

1. Problem-solving takes place as soon as the problem is perceived by the problem solver and is aimed at to reach the goal stated by the problem. The problem is supposed to be not only new and novel but also at the same time, there is supposed to be no direct solution available to the problem solver at the time of its presentation. Moreover, it is also assumed that the problem solver possesses the basic information needed to solve the problem.

Definitions of problem solving vary from the 'simple finding of exceptions' (Hazlitt) to 'formal reasoning of a complex nature' (Piaget). Problem-solving has also been defined as 'combining the essentials of two isolated experiences' (Maier) or as 'the integrated activity of perceptions, memory, recall, association, generalization and reconstruction of ideas' (Welch). Equally different are the problem situations used. They vary from 'cats in puzzle boxes or rats in mazes to adult human beings solving complex problems involving space and time relationship resulting in different explanations of the nature of problem-solving which are not so much correct or incorrect hypotheses as they are descriptions of behaviour that has been evoked by different types of problems at different levels of difficulty'.

2. The basic problem is to generalize from the problem-solving behaviour evoked from entirely different problems. Here we should keep the specific characteristics of the various

problems to themselves in order to pinpoint more on problem-solving rather than on the psychology (typology) of the problems. Sometimes it is very difficult to distinguish between learning situation and a problem situation because the former does present a problem situation of one kind or the other. Similarly, even the most abstract problem presents certain aspect of learning : ('from perceived data, trial and error') which makes the distinction quite difficult right at the beginning of the experiment. Learning to tie a knot is a problem when faced initially. Largely speaking, we can say that we speak of a problem when its solution is either by logic or by insight (Munn)

3. Brownell fixed problem somewhere intermediate in a continuum having puzzle type at one end and familiarity and complete understanding at the other end. He also points out the artificiality of 'separating problem-solving from other learning tasks because the same objective situation may be seen differently by different persons e.g. a puzzle for some, problem and a thorough familiarity for the rest'. In problem-solving, the role of memory should be minimum. Lastly, he adds that a problem solver should be able to understand what he is supposed to do while tackling the perceptual and the conceptual task embodied in the problems unknown to him. At the time of their presentation, he may experience 'perplexity' but should not suffer utter confusion.

4. J. Stanley Gray regards problem-solving behaviour, of course, a process, but also adjustment with difficulties and interferences encountered in a problem situation. It is a way of proceeding in spite of interferences. He suggests the following methods of problem-solving :

1. Unrelated and habitual bahaviour.
2. Insight behaviour.
3. Blind trial and error behaviour.
4. Vicarious behaviour.
5. Behaviour designated as Scientific Method.

The method, of course, depends upon the nature of the difficulty inherent in problems.

5. In classroom situations, problem-solving can be viewed from two angles, a way of thinking or learning and a way of

teaching. Psychologists have investigated and are interested in the former aspect, that is, as a way of thinking which occurs only "when there is a need for it, when the situation is baffling or unsatisfying or when the situation presents a difficulty that cannot be met by other means". The teachers are interested in problem-solving as a way of teaching. The research findings from these two angles could well be complementary ; and highly useful both in developing the science and art of teaching.[7]

After considering the varied views on problem-solving, we have tried to disentangle it from three allied areas, namely thinking, reasoning and learning by defining problem-solving as —what takes place as task—oriented situation is provided to the problem solver and is aimed at to reach the goal. It however becomes necessary to qualify the word 'task' keeping in mind the aims of investigation.

Logical steps in problem-solving

Dewey, on the basis of introspection, has suggested five steps in thinking which explain most of the aspects of our thinking. These steps are : 'a felt difficulty, its location and definition, suggestion of possible solution, development by reasoning of the bearings of suggestions and further observation and experiment leading to its acceptance or rejection ? Others in turn have suggested their own steps following more or less the same pattern : Burt (1928), Gray (1935), John (1944), Polya (1945), Humprey (1948), Bloom (1950), Burrack (1950), Vinacke (1952), J. Stanley Gray (1956), and Mills and Dean (1960). Mills and Dean mention the following steps in logical solutions of the problems :

(a) A difficulty is recognised.
(b) The problem is clarified and defined.
(c) A search for a clue is made.
(d) Various suggestions are made, and are evaluated and tried out.

Whereas practice in the definition of problem-solving involves :

(a) Problem survey : Analysing a potential problem situation for items to be studied.

(b) Problem description : Providing a clear statement for items to be studied.

(c) Problem discussion : Making sure that the students understand what is involved in the problem.

(d) Problem limitation : Isolating those parts of the problem that can be attacked profitably.

(e) Planning for action : Preparing suitable hypotheses for investigation.

(f) Further analysis and limitation : Tentative testing of hypotheses to identify those most likely to yield solutions.[8]

The above-mentioned steps in problem-solving are not final and need not necessarily follow each other in the problem-solving process. They are, in fact, 'simplified, idealized versions of what may take place in problem-solving. They are heuristic rather than rigorous proofs'. There are other workers who saw stages in problem-solving, for example, Selz and Duncker. With the passage of time, these steps have acquired 'natural status'. Each step in problem-solving resembles a learning set. Duncker in 1945 elaborated the concepts of set, determining tendency and anticipatory scheme from the Wurzburg school into the more generalized concept of search model called Strategies (Goodnow and Austin) or some 'key factor' (Guilford, Merriefield, Christenson and Frick), later on, in determining the effectiveness of creative thinking.[9]

Formulation and testing of hypotheses

Steps in problem-solving do not guarantee solutions. It is the investigator's job to apply these steps imaginatively so as to break the problem at its weakest points. If he does it, his way or approach of discovery becomes sooner or later an integral part of the scientific methodology. In this enterprise, setting up and testing of hypotheses come handy to him. If there are no hypotheses to a particular problem (particularly speaking, experimental), it means that the whole problematic situation is opaque to the investigator. He has then nothing else to do but to drop the problem. Hypotheses are therefore nothing but tentative stabs at the problem, powerful beacons which light up unknown paths, 'outstretched arms' to grasp the truth or suggested answers to the problem. They are neither true nor false. They are either accepted, rejected or partially accepted. They are therefore not the positions to be defended as in a debating society. The characteristics of good hypotheses are their simplicity sharpness, adequacy, verifiability, testability, and more importantly, availability of frame of reference for stating conclusions. It was Galelio who, before going to the university, discovered that the time period of a simple pendulum depends solely on its length.

It is not exactly known how the hypotheses arise in the minds of individuals. It is still a dark continent. Discoveries have to do more with hypotheses than with data collected unintentionally. Creative thinkers set up and reject a number of hypotheses. This situation is analogous to trial and error learning, and according to Munn develops in four stages, namely, preparation, incubation (conscious as well as unconscious activities), inspiration (sudden emergence of the idea) and verification or revision. Like steps in problem-solving, this situation is also not clear cut. There are many circles and circles on circles in this cycle of creative thought. Hypotheses originate both from theory and facts. They may originate at different levels of development as well as depend upon the imaginativeness of the investigator.

Scientific methods

Like the definition of science, it also defies it own definition. Scientists attack problems or even the same problem in diverse ways. They attack the problem at any point they think proper. The choice of the method or a group of methods always rests with the scientist because his main aim is to catch the fish rather than to specialise in the art of angling (about which he least bothers). However, he thinks of several ways or hypotheses for cracking the whole puzzle or a series of tiny puzzles as he comes across them. There is, of course, unconscious awareness in regard to the relevance of a particular method under consideration. Secondly, at the scientific frontier, there is no official line of attack available. Scientific methods are used to standardize knowledge which are as standard as the prevailing conditions allow or keep them unchallenged. Scientific statement changes as the conditions under which it is supposed to be true change. Ohm's Law is true only when the physical conditions on the conductor do not change. Boyle's law is not true at all temperatures. If one takes a historical view, it appears that scientific knowledge on a given problem has been quite variable in different periods. Each advance is something successfully won from nature for possibly rich exploitation later on. There is an interesting example in the history of physics where father (J.J. Thomson) and son (George Thomson) received nobel prizes in 1906 and 1937 respectively by using scientific methods for, proving two opposite views on the same subject', the two views respectively were that electrons were particles and waves. This is not the only example. History of Science is full of such examples. It is an example of productive thought which it is difficult to confirm or reject partially at its very birth. It is only through scientific methods followed by rich constructive imagination and speculation (testing and retesting under as many diverse conditions, as humanly possible) that a given productive thought grows gradually to its adulthood, not again to remain unchallenged for centuries like water (considered one of the few basic elements) which on passage of electricity turned out to be a compound of hydrogen and oxygen. Fundamental ideas of science remain fundamental until they are challenged in turn by workers successfully : Ptolemy, Copernicus, Kepler, Newton and Einstein. In the words of Albert Szent-Gyrogi, 'Research is to see what everybody has seen and to think what no body has thought'.

Steps in scientific method

Before Karl Pearson, philosophers and others had speculated on the nature of scientific method. But it was left to Karl Pearson who gave it its modern form. If strictly followed, it is likely to give firm results. In Karl Pearson's scheme, the following seven were the major steps of scientific method :

1. Sensing the problem including its definition, scope and analysis.
2. Experimentation.
3. Collection of data, interpretation of data, selecting and examining the most fruitful hypotheses and arriving at

a tentative solution.
4. Establishment of the law.
5. Generalization of the law (theory).
6. Application of the law to new situations.
7. Predictability.
8. Idealization and abstraction. This step tends to link science with philosophy.[10]

Logically speaking, there is nothing wrong with these steps. They are just the precautions to be observed or stages to be mastered in the course of solving a given problem. They do not at all guarantee either solution or clarify any psychological principles. As already mentioned, we, in fact, know very little, how the scientists, from the psychological angle, encounter creative problems which result in the arousal of various hypotheses in their minds or what makes them attack problems ? One can only judge at the end for the basic problem any way is how to crack the problem at its joints. Steps may not help consciously as well as unconsciously. According to P.W. Bridgman, in problem solving, 'no holds are either barred' or restrictions imposed except the dictates of the problem itself. Scientific method need not necessarily be followed when a quick, qualitative and cheap solution is required.

4. Science as Past Adventure

Leeuwenhoek worked for twenty years without an audience. This janitor and shopkeeper wrote a paper on : "A specimen of some observations made by Microscope Contrived by Mr. Leeuwenhoek concerning Mould upon the Skin, Flesh, etc., the Sting of Bee", etc. The Royal Society of LONDON requested him to send further details about his microscope as well as method of observations. Regarding his observations, he would send affidavits from prominent citizens of Delft rather than the mysterious details of his priceless microscope. He said, "How I wish, Sir, that I could show you my best lens, with my special way of observing, but I keep that only for myself and do not show it to any one, not even to my own family." I do not want to teach the art of grinding because then I will have to teach many. I do not want to introduce slavery in my art. To Leibnis, he said :

The professors and students of the University of Leyden were long ago dazzlend by my discoveries, they hired three lens grinders to come to teach the students, but what came of it ? Nothing so far I can judge, for almost all of the courses they teach there are for the purpose of getting money through knowledge or for gaining the respect of the World by showing people how learned, they are, and these things have nothing with discovering the things that are buried from our eyes. I am convinced that of a thousand people not one is capable of carrying out such studies, because endless time is needed and much money is spilled and because a man has always to be busy with his thoughts if any thing is to be accomplished.[1]

Support from wife. There is nothing in me to attract a young girl's fancy but my recollections tell me that those who have known me very well have loved me very much. So she married the man who was on the verge of cracking mysteries. Madame Pasteur not only awaited him at night for thirty six long years but also believed in him. She wrote to his father, "You know that the experiment he is undertaking this year will give us, if they succeed, a Newton or a Galelio". Pasteur was her life and since Pasteur thought only of work, her own life melted more and more into his work. . . . .

Where in your families will you find a young man whose curiosity and interest will not immediately be awakened when you put into his hands a potato, and when with that potato, he may produce sugar and with sugar alcohol, and with that alcohol ether and vinegar ? ... He challenged all. 'Am—I—not—clever-to have found—this; and are not—all—of you—fools not—to—believe—it—at—once. ... In 1882, he gave a speech in an International Conference at Geneva on "How to guard Living Creatures from Virulent Maladies by Injecting them with weakened Microbes". He made several claims mentioning little about his miserable failures. There Dr. Robert Kock, who developed his art of experimentation from a microscope gifted on his birthday retorted back :

Did Dr. Pasteur say that his first vaccine would kill mice, but not guinea pigs ? Dr. Kock had tested it, and it would not even kill mice. But some queer samples of it killed sheep ! Did Mr. Pasteur maintain that his second vaccine killed guinea—pigs but not rabbits ? Dr. Kock had carefully tested this one too, and found it often killed rabbits very promptly—and sometimes sheep, poor beasts, which Mr. Pasteur claimed would guard from death ... Finally, was Mr. Pasteur really burning so with a passion for truth ? Then why had he not told of the bad result, as well as the good ones, that had followed the wholesale use of his vaccines ? Such goings—on are suitable for the advertising of a business house, but science should reject them vigorously.

Did Kock dare to make believe that Pasteur's vaccines were full of contaminating microbes. For twenty years before Kock's scientific birth in 1876, it has been my one occupation to isolate and grow microbes in a pure state, and therefore Kock's insinuation that I do not know-how to make pure cultivations cannot be taken seriously.

P.C. Ray, the Father of Indian Chemistry, illustrated his Chemistry lectures from many viewpoints : historical, economic, political, personal, and commitment to profession in the face of colonial rule. He would try hard to build a bridge between the minds of his pupils and those of the masters of the modern Chemistry like Priestley, Scheele, Lavosier, Cavendish, Dalton, and the consequent devotion and dedication required in the persuit of science. He feelingly as well as admiringly talked of the pilgrimage of Wohler from Germany on foot to the house of the great Swedish savant Berzelius, where Anna, the Kitchen maid, served as the laboratory assistant. He taught chemistry but not the Syllabus of the Calcutta University, and would humorously advise his students to make a bone fire of their so-called text-books, notes, compendiums, digests, etc. for they produce parrots licensed ignoramuses. In 1934, on becoming the first President of the Indian Chemical Society, and in reply to the message of congratulations from the President and the Council of the London Chemical Society, he observed :

> More than forty years ago while a student at Edinburgh, I almost dreamt a dream that, God willing a time would come when modern India will also be in a position to contribute her quota to the world's stock of scientific knowledge; and it has been my good fortune to see my dream materialise.

Introduction

Science is a vast body of knowledge, doubling at the end of each decade, in this century. It has been developed by the efforts of dedicated philosophers, priests and scientists over the last several centuries. The story of the development of the incomplete house of science or the historical dimension to the development of science is as exciting and fascinating as current scientific research. It informs us intellectually and emotively about the varied imaginative modes of inquiry which developed and influenced our present day outlook and civilization. Nay, it still goes further by providing us a real raw inside viewpoint of the Nature and Spirit of Science in significant periods of human history from intellectual and emotive aspects by familiarizing us with the nature of scientific enterprise and its advance : methods and tools of science ; role of apparatus, observation, experimentation and drawing inference ; personal characteristics of scientists, maintenance of communication links among scientists ; and lastly, the 'interplay of social, economic, technological, and psychological factors' associated with the growth of science itself. It is no wonder then that the historical dimension to the study of science tends to place even current scientific knowledge in its true perspective. It gives its devotees and men of less calibre like most of us inner strength to push forward regardless of consequences in the face of personal, psychological, sociological and financial difficulties. It as well enlightens us to the contributions of each scientist in a given period as well the cowdung (unsolved problem) still left by him. How is it that a giant of his age stumbled and stumbled against a problem or a new scientific fact despite his 'power of observation, originality of imagination, virility of ideas and a remarkable capacity for philosophic and scientific narration." And how is it that the same giant succeeded generously by reasoning carefully even with vague concepts which were later accepted by his successors. To quote Bacon and Mashina Yukio :

> The history is obliged to penetrate into the very soul of every age, and every author, to relate faithfully and impartially the thoughts of all, and to maintain every one in his right, not giving to moderns what belongs to the ancients.
>
> The past does not draw us back to the past. There are certain memories of the past that have strong steel springs, and when we, who live in the present, touch them, they are suddenly stretched out and they propel us into the future (1).

The use of history in science teaching both in the basic education of professional scientists and arts graduates, leave apart the school population, is a neglected territory in our country. Like literature, the students of science need not at all study the great classics of science, for example, physica of Aristotle, Almagest of Ptolemy, Principia and Optics of Newton, Electricity of Franklin, Chemistry of Lavoisier, Geology of Lyell, and the Origin of Species by Darwin. They study, say, the present Chemistry not the past Chemistry which led to it, that is, Pauling not Priestley. Aldous Huxley, the grandson of J. H. Huxley had exactly this in mind when he said :

> Every generation of scientific men starts where the previous generation left off ; and the most advanced discoveries of one age constitute the elementary axioms of the next. We are not in the habit of inspecting the foundations of the houses in which we live ; and similarly, men of science are not in the habit of referring to the original paper of their predecessors.[2]

We lose much of value if this attitude remains in the remaining half of the so-called Century of Science. Of course, the physical world does not change but our concepts about it are changing fast. We thus keep the citizenry ignorant of the ways the scientific ideas and techniques change and influence our actions and thoughts in their historical perspective. In the absence of this knowledge, how will they exercise their choice when they are asked to vote on the utility or futility of manufacturing a hydrogen bomb, support pure research or applied research, fluoridation of water, compulsory B. C. G. vaccination, atomic bang for peaceful purposes and other scientific issues which sooner than later in no time become political, social, economic and moral ones. Lastly, history in science helps us to see present in relation to the past, future in relation to the present ; and illuminating in the process, the nature of human adventure committed to progress on consequent discovery and development in the face of even near unsurmountable difficulties

Illustrations from the History of Science

Let us exemplify part of the above-mentioned ideas with several incomplete illustrations drawn from the History of Science. There is another regressive approach to tackle this problem. Take any one of the modern ideas and trace its origin backward by showing its complete mix up with other general ideas right upto the point of its extinction in the distant past. Draw its flow diagram and watch the entire development over several centuries, quite an intellectually satisfying experience. Now consider the following examples :

1. The Concept of Electron.
2. Christopher Columbus on a Voyage of Discovery.
3. The Bending of A Seedling.
4. A Mysterious Nervous Disease.
5. The Discoverer of Some Chemical Elements.
6. The Work of Ronald Ross.
7. Our Universe and The Shape of Earth.
8. From Jungle to the Zoo (The Periodic Table),
9. Our Foods ; and the Story of Vitamins.
10. The Origin of Life.

11. The Emergence of Electron.
12. The Work of Humphery Davy.
13. The Inventive Wizard, George Westinghouse.
14. On Measuring the Velocity of Light.
15. The Use of History of Science Cases.

1. The concept of electron

Take the concept of electron which is increasingly becoming difficult to visualize. It is conceived differently in different theories. Stoney, the originator of this concept, meant by it a basic unit of positive or negative electric charge. Through his experimental studies, J.J. Thomson made it observational by carrying on this particle a negative unit of electricity. He won a nobel prize. Later on, his son showed electron like a wave and also shared a nobel prize. By using scientific methods, both won nobel prizes for contradictory results. Now it is claimed that electron has a dual character. It is also of interest to point out that Schrodinger regarded electron as a 'theoretical term, designating packets of the maxima of interfering phase waves in non-mathematical configuration space'. This example shows that it is possible to reason carefully and successfully even with vague concepts. What is electron, therefore, receives different answers from different people.[3] Better conceptual distinctions can be obtained only when concepts in vogue along with their past history are clearly known (N.R. Hanson).

2. Christopher Columbus on a voyage of discovery

The Voyage of Christopher Columbus shared many features of a classical discovery. He firmly believed that the earth was spherical rather than flat. He therefore, thought of reaching East by sailing West. He was aware of three different estimates regarding the diameter of the earth. He planned his voyage in the light of one of the estimated diameters which was not far wrong—from the actual diameter. He encountered all sorts of difficulties, physical psychological and financial. In addition, he had to discipline his crews as well. He did not discover the hypothesized route but instead discovered a new continent. He did not believe in his new discovery. He stuck rigidly to his original hypotheses that he had discovered a way to the Orient. Hardly anybody in his life time fully realized the implications of his discovery. Consequently, he received little reward or credit. The moderns gave him the credit later on. Now new evidence indicates that he was not the only first European to reach America[4].

3. The bending of a seedling

Science is a matter of 'meticulous observation and unrestrained speculation' (Eric Ashby). Merely counting the teeth of a horse, donkey or man does not constitute an act of science. It is only a step towards it. It tends to become science only when one attempts to describe the number and arrangement of teeth in different animals called dentition. Efforts become quite powerful if they result in the discovery of a mathematical relationship. Thus it becomes possible for one to 'Assign the bewildering diversity of mammals to one or other of a few easily remembered categories'. Let us illustrate :

All of us know or it can be verified any way that an oat seedling when placed near a window bends towards light. The bending occurs at a point just over 6 mm away from the tip. The question arises : What is the cause for this bending ? Charles Darwin also observed this phenomenon. He found further that bending does not occur in case tips are removed or covered with tin foil caps. He hypothesized that the tip gets something from light ; and in turn transmits a message below for the bending to occur. Boysen-Jensen confirmed Darwin's observation ; and followed up this observation by showing that Seedling grows vertically in uniform light ; and the Oat Seedling ceases to grow in case its tips are cut off. They made another interesting observation. This phenomenon repeates itself when the severed tip is put back on the stem itself. They, therefore, concluded that there is something (Stimulus) in the tip which not only controls bending in oblique light but also maintains straight growth in uniform light. Now another additional subsidiary hypothesis appeared. The severed tip, if replaced on the stem, is also able to transmit the stimulus. Now the question arises : what causes the stimulus ? At this point, they further hypothesized that stimulus is either a nerve impulse (Electric current) or some chemical substance. This could be tested by placing a minute cube of gelatine between the severed tip and the stem. The choice of the gelatine cube rested on the fact that the nerve impulse and not the chemical substance would be fully resisted. In 1928, Went in Holland thought of collecting this chemical substance in blocks of gelatine and succeeded in his efforts. Whereas he failed to name the substance, he did succeed in an other direction. He developed a technique in collecting this substance in the tip in certain units. Kogol, with careful experimentation, collected this growth promoting substance in sufficient quantity, analysed it, isolated it, and named it as 'Auxin'. Fifteen years later, it was found that it was not 'Auxin' but some other simpler substance. It is in the tradition of science, where the credit is due, the name of Kogol is just not mentioned.

It is interesting to note that it took about seventy-five years for partial understanding of this problem when Charles Darwin gave his first vaguely worded hypothesis. Currently, the position is that the efficient cause of growth as well as the cause of bending in an Oat seedling is known to be a chemical substance. Not only the constitution of this chemical substance is known but also the chemists have succeeded in synthesizing it. Several additional investigative questions have turned up during the solution of this one time least understood problem. For example, 'Why is it that only this substance and not other substance with similar chemical composition helps in growth ? Is it suggested that it is related to the specific configuration of atoms in this substance' ? 'What other growth promoting substances critically control plant and animal life'? Science appears to advance forward by unfolding a chain of mysteries.[5]

4. A mysterious nervous disease

W. H. Bennetts investigated a mysterious nervous disease which inflicts sheep in Great Britain and Australia. He first hypothesized that this might be due to lead intoxication. He, therefore, treated some sheep with ammonium chloride. The initial results appeared to be quite promising but the latter were not. From this, he got a clue that this might be due to some mineral deficiency. He followed up this clue; and through experimentation pin-pointed the cause of this strange disease, namely, the deficiency of copper. It had never been even suspected in the past that the deficiency of copper ever produced a disease in an animal. At this moment of triumph, his thoughtful remark needs careful consideration : Hypothesis is neither right nor wrong nor definitive; and it simply attempts to direct our probings.[6]

5. The discoverer of some chemical elements

Let us consider the work of William Ramsay (1852-1916). In 1785, Cavendish passed electric sparks in a mixture containing atmospheric nitrogen and excess of Oxygen. On removing nitrogen Oxide and Oxygen, he found that a very small quantity of the gas was still left which, of course, did not exceed 1/120th of the original volume of nitrogen. On reading this account, Ramsay had noted : 'Look into this'. He possibly forgot all about this but was soon reminded by Lord Raleigh's Open letter in 1892.

> I am much puzzled by some results as to the density of nitrogen and shall be obliged if any of your chemical readers can offer suggestions as to the cause. According to the two methods of preparation (Nitrogen gas), I obtain quite distinct values. The relative difference, amounting to 1/1000 part, is small in itself, but it lies entirely outside the errors of experiment.

Ramsay joined Lord Raleigh and both of them now attacked this problem jointly. They discovered a new gaseous element, namely, Argon. This was not the end of journey for Ramsay. He made a strenuous search for all the possible compounds of Argon. He even studied several minerals containing Uranium which, on dissolution in acid, released a gas presumed to be nitrogen. He found that the released gas was not nitrogen as hypothesized by him earlier. Of course, it certainly contained Argon but there was another gas, hitherto, unknown on earth. On spectral analysis ; it gave a clear and brilliant yellow spectral line. Here is another example where two independent scientific paths happen to cross each other. Earlier a French astronomer had found this line in his spectral studies, on the atmosphere of the sun. Further, Frankland and Lockyer stated that this line was due the existence of a new element in the sun for which they had suggested the name of Helium. A small anamolous observation on being followed up by careful and extensive experimentation, systematic analysis and flash of imagination brought down helium from the sun to our abode. About this discovery of Helium, Ramsay wrote to his wife on March, 24, 1895 as follows :

> Let us take the biggest piece of news first. I bottled the new gas in a vacuum tube, and arranged so that I could see its spectrum and that of Argon in the same spectroscope at the same time. There is Argon in the gas ; but there was a magnificent yellow line, brilliantly bright, not coincident with but very close to the sodium line. I was puzzled but began to smell a rat. I told Crookes, and on Saturday morning when Harley, Shields, and I were looking at the spectrum in the dark room, a telegram came from Crookes. He had sent a copy here and I endorse that copy. You may wonder what it means. Helium is the name given to a line in the Solar spectrum, known to belong to an element, but that element has been hitherto unknown on earth.—It is quite overwhelming and beats Argon.

In 1898, he reported other gases like neon, krypton and xenon, and radon (radium emanation). Let us sidetrack for a while here. It is of interest to note that an American scientist named W.F. Hillebrand had examined a sample of mixture containing both Argon and Helium before 1890, but had failed to identify correctly. He discovered that certain minerals on reaction with acid gave off nitrogen. He repeated the experiment and found that the newly evolved gas was not nitrogen but a mixture of gases containing Argon and Helium. Ramsay investigated thoroughly and successfully whereas the American scientist remained very close to this discovery. After Ramsay's success, he had these comments to make on his failure :

> The circumstances and conditions under which my work was done were unfavourable ; the chemical examination had consumed a vast amount of time, and I felt strong scruples about taking more from regular routine work. I was not a novice at a spectroscopic work of this kind. It doubtless has appeared in comprehensible to you, in view of the bright Argon and other lines noticed by you in the gas from clevite, that they should have escaped my observation. They did not. Both Dr. Hallock and I observed numerous bright lines on one or two occasions, some of

> which could be accounted for by known elements—as mercury, or sulphur from sulphuric acid ; but there were others that I could not identify with any mapped lines. The wellknown variability in the spectra of some substance under various conditions of degree of evacuation of the tube led me to describe similar causes for these anomalous appearances, and to reject the suggestion made by one of us in a doubtfully serious spirit, that a new element might be in question.

Who are wise before the event ? Only a few ! Who can pinpoint discovery with absolute confidence at the scientific frontier ? The answer is obviously No one ? Here, one has to learn to believe in one's own answers without raising an accusing finger at any body who may give false scent. The price for this is that one has to spend not only hours and hours but days and months, in isolation, on the solution of a given problem. Both choose and chase are important where in, factor of chance, is not barred, one finds choose which was not the object of chase. In the process, it is no wonder that one has to tolerate lot of vagueness and consequent resulting confusion for a long time. To quote Peter J. W. Debye :

> It is the urge to understand that makes me study things. Perhaps in the experiment something happens that astonishes me. I think about that it could mean-try this, try that in my mind. Discontent pushes [me. It is discontent that is the driving force, soon I become impatient, and then I get no where, So forget about it and then, months later, the answer suddenly comes to me. Once I have it and have tested it that it is the right answer, I lose interest. I was to explore something new.

Ramsay's contribution is unique in the history of the discovery of chemical elements. No other individual, single handed, had discovered a whole column of new elements in the periodic table. The chemical inactivity of elements gave his work extra distinction. After his chemical discoveries, nature need no longer jump abruptly from halogens to the alkali metals differing completely in electropolarity.[7]

6. The work of ronald ross

Let us describe in brief the work of Ronald Ross on malaria who was a reluctant medical doctor in the Indian Medical

Service. People living in the tropical countries know first hand about the terrible effects of malaria on their physical and mental health. In our country, a large number of people used to die of malaria every year. It is interesting to note that even recently, Indian doctors, on seeing a feverish patient, used to treat him first for malaria than for any other disease. The situation is now much happier and better for malaria has been brought under control in our country. This happened because Ronald Ross discovered the causal agent of malaria.

It is of interest to point out that the cause of malaria had been speculated upon by many learned people within the last 2500 years or so, Hippocrates, for example, described this disease quite elaborately. The Greeks guessed rightly and believed that malaria was associated with marshy lands, filthy water, stagnant ponds and impure air. Herodotus even mentions that Egyptians were the first to use nets for protecting themselves from mosquito bites. About 1600 years ago, a Roman agriculturist named Palladius found that the drainage of marshes reduced the incidence of malaria in the neighbourhood. He suggested two other causes of malaria, namely, the drinking of water containing mosquito grubs by the inhabitants ; and biting by the mosquitoes. Since then, part personal experiences, observations and descriptions began to accumulate but at the end of the nineteenth century, it was not clear how the people caught malaria as well as how it could be fought effectively. Ronald Ross did it despite the fact, he was not a trained biologist. His work was also of significance in other insect borne diseases like yellow fever, sleeping sickness, typhus and plague.

He was a man of extensive interests running across several disciplines with which we will not deal here. As a boy and an army surgeon in the Indian Medical Service, he had seen lot of malaria which stirred his conscience beyond measure and description. He intended to do something about it. His serious interest in mosquitoes began in 1884 when he was severely bitten by them at Bangalore. In 1888, he undertook a course in bacteriology which provided him some rational knowledge of sanitation. It is of interest to mention here that he fared very poorly in the new diploma of public health examination. His examiners passed him because he showed his ingenuity in answering a non mathematical problem on population mathematically which was least expected in that question. On return to India in 1889 after his usual leave, he began his systematic investigations of mosquitoes by breeding them from larvae. As a first shot, he discounted the discovery of Laveran, a French Biologist, that malaria was caused due to a parasite in the blood. He could not find them in blood and showed so to his colleagues. He felt keen frustration for he had at his age achieved nothing in his life. In 1892, his father died, an event which made him very sad. Two years later, he again went to England, wrote a novel, won a Parkes Memorial Prize on writing the best essay on malaria. In this essay, he rejected the Bad Air Theory of Malaria by arguing that a 'Square yard of infected soil does not cause as much infection at a distance of one yard as a square mile at a distance of one mile', an hypothesis in close agreement with his past experience in India. Here, he met Patrick Manson who showed him the malarial parasite which he had failed to identify in blood in India. He made Manson, his friend, philosopher and guide. He advised him : "Do you know, I have formed the theory that mosquitoes carry malaria just as they carry the parasite of elephantiasis' ? He suggested him to investigate the stage development hypothesis as intensively and carefully as possible. At this stage, he also improvised his own small high power microscope which he called a diagnostic microscope. He now went straight to the heart of the problem vaguely knowing where the heart of the problem lay. In this darkest hours during investigations, he was to remain in touch for intellectual and emotional support from Manson who generously offered him his whole knowledge, skills and experience. It was, of course, left to Ross to pick and choose or to tear into the problem any way he deemed best. He now sought for parasites in patients suffering from malaria in Secunderabad. He then tried hard to find parasites in the mosquitoes themselves. With difficulty, he got volunteers who were made bitten inside nets by mosquitoes. He even went to the extent of breeding his own mosquitoes whose past history he knew quite well. He recaptured them after they had done their biting business. He dissected them and looked searchingly for parasites. He encountered many problems both personal and professional when engaged in this work. He was usually the last person to be promoted ; and hence constantly remained in financial difficulties. He requested in vain for some minimum facilities and leave. His friends considered him a crank for he was challenging an age old traditional cause of malaria. The professional zoologists accused him of handling the problem crudely for he attempted to isolate a huge task 'without professional training in natural history and microscopy'. One can imagine his task what he recorded when he saw a mosquito under a microscope :

> Appears as big as hippotamus is to the naked eye, and the object I was looking for need not necessarily be larger in comparison than, say a nut or an apple ; and moreover, we had no clue at all as to the position the parasite would take up in the enormous mass of cells of which mosquito is composed.

It is now known that there are over two thousand species of mosquitoes out of which only one transmits malaria. Through his investigations, he pinpointed on about five different malarial parasites. He was thus solving a problem in which there were two unknowns to be discovered in two equations. He had, therefore, to solve this problem through permutations and combinations, that is, by the method of elimination, He surmounted the ensuing difficulties like a Hercules by 'dissecting mosquito after mosquito' and observing each of them intensively for over three hours under his improvised microscope. His sweat had rusted the screws of his microscope. But in the midst of his difficulties, he saw the relevance of his work for the suffering humanity. Manson had told him not to despair on the Mosquito Theory of Malaria.

> Look on it as a holy Grail and yourself as Sir Galahad—Look on a stone wall as a stimulant rather than as an insuperable barrier to progress. I have run my head against them often enough, but some how if I kept hammering at it and thinking about it sooner or later I got over or under or through when I had set my mind to it ; and so will you.

He stuck to the problem. He had with him about thirty potential cases of mosquitoes left which, on further close examination, were reduced to three. At this moment, he had not succeeded in tracing the parasite inside the body of the mosquito. His depth of frustration knew no-bounds. He was nearly at the breaking point. Luck favoured him when he saw some circular object with distinct black granules in it like those he had earlier seen in the malarial parasite. He did his usual chores, that is, made notes and drawings. He had now one mosquito left. He now hypothesized that circular object he had noticed, a little while ago, must grow over night in the last remaining mosquito if it was a stage in the development of the parasite. He was now considering several alternatives at the same time, next day, he confirmed what he had hypothesized. He had now successfully traced the various stages of the parasite or the cycle of malaria. He scribbled the following lines :

This day designing God
Hath put into my hand
A wonderous thing. And God
Be praised. At his command
I have found thy secret deeds
Oh million-murdering Death
I know that this little thing
A Million men will save
O death where is thy sting ?
Thy Victory or Grave.

He was in a state of ecstacy. A month later, he was sent to the frontier despite his heart in malaria. This further interrupted his work for two years. In 1898, Manson reported personally the results of Ross to the British Medical Association. His results were sensational in many ways. This was not, however, the end.

It is not rare in the history of science that two or more than two persons tackle the same problem differently and that also more or less at the same time. One such person in Italy was a Medical doctor turned into a highly trained professional zoologist : Giovanni Battesta Grassi. He was the exact opposite replica of Ross who was illogical and anti-scientific in his fierce mad pursuits. He was not like Edison who got the things first; and theories later on from the professors. There is then no logical solution to the problem but the one characterized by hit, trial, exclusion and success, if luck favours. He began to publish his researches on malaria by mosquito bites, but after the publication of Ross's first paper. He further showed that malaria both among birds and man was transmitted exactly in the same manner. Interestingly enough, unlike Ross, he progressed, a lot towards his goal without carrying a single serious experiment. The moralistic situation was the same in both cases. Malaria was one of the worst problems that Italy faced in his time. So his pursuit was also driven by a humanitarian consideration. He offered himself and his friends for mosquito bites at considerable personal risk. He found mosquitoes without malaria but never malaria without mosquitoes. He, therefore, concluded that there must be a special kind of mosquito which he must discover. He obtained state assistance and set up several control experiments. His technical work supported the main thesis of Ross but increasingly, he began to stake his claim for the original discovery. This upset Ross badly who hurled abuse on Grassi by paying that he was a thief, and charlatan who had added nothing to the original evidence. It is a bit controversial whether B. Grassi in his enthusiasm forgot to pay his debts to the past workers. Robert Koch called him a scientific thief. Even Laveran found his case unconvincing, shabby and dishonest. After his retirement from army, Ross got a lectureship at the newly started school of Tropical Medicine in Liverpool.

In 1902, he won a nobel prize carrying a sum of seven thousand eight hundred and eighty pounds for his discovery. He died in extreme financial difficulties thirty years later. His last words were, 'I shall find out things—yes—yes'.[8] It should not be forgotten that Ronald Ross was not alone who did not make, when young, good impression on his father. It is interesting to note that to win an insect collecting competition, Charles Darwin even went to the extent of putting one insect alive in his mouth for he had no space for it in his collecting bag. His father said to him, 'You care for nothing but shooting dogs and rats catching, and you will be a disgrace to yourself and your family'. Later on, he timed his daily physical activities and succeeded to complete his treatise despite very bad health. Such people have zeal, ability and are also talented. Their minds engaged on problems tend to be stronger than their physical frail bodies. This usually happens when they fully identify themselves with their problems. Lady Parson at the death of her husband, Charles Algernon Parsons, said perhaps in a similiar vein :

> The outstanding feature to me of his whole life was his power of concentration nothing disturbed him when he was absorbed in a problem—no noises, no discomfort, no time and no meals. He was perfectly oblivious of them all. The other great feature was his sublime courage. He never admitted defeat ; he was always hopeful about any concern he undertook, and looked forward, even in his last days, to make a success of the new kind of work he had undertaken when well over the age of seventy years.[9]

7. Our universe and the shape of earth

Curiosity in man has been as old as man himself. He has pushed back the unknown in his white heat of creativity. According to Bentley Glass, it should be the job of teacher to open up the frontiers of science before the very eyes of his brilliant pupils so that most of them are attracted by the challenges of the unknown. To quote Bentley Glass :

> Narrow is the gate and rough the way into the realm of scientific explorations and discovery. One must know many hard facts, assimilate many concepts, become practised in many skills and techniques. One must become disciplined, which means to learn persistence in the face of preliminary failures, and to exercise ingenuity when a particular attack on a problem is blocked. Because these truths are so often emphasized, many young persons of scientific gifts and inclinations are discouraged too greatly at the outset of a scientific career, and decide to enter some other pursuit. A love is better than none.[10]

One should not be surprised, if on surveying scientific literature, one finds that science is dogmatic, that is, great scientists do not change their ideas or concepts so easily as is generally assumed when a new evidence or conflicting evidence appears. A new concept has therefore to be more powerful or fruitful than the one it replaces. This constitutes, in the face of new concept, the cumulative aspect of science whose ore, of course, can be further refined. Another more interesting aspect of science is that it is possible to reason or figure out things even with untruths like vital force ; and elusive and vague concepts like phlogiston. In science, window tapping is allowed so as to have an inside feel about the growing body of science and crack it at its weakest point. It is just possible that nothing may appear in the cracked nut. It is a case of false scent then. Failure in science is as revealing as positive contribution : searching for a black cat in a dark room where black cat does not exist. Who can pronounce this judgement ? It has to be shown so. The balance of thinking then shifts to discovering new facts and relationships even at the cost of discarding the entire past stuff. The situation is thus set right ; and new scientific theory is thus born by discovering something new, unthought and unheard of hitherto. It is thus a problem of Talents and Tools demanded by discovery when we land ourselves into theoretical and practical oddities. Unlike bad workmen, we have to quarrel with them (tools) in order to bring into the open the hidden notions underlying a complex scientific phenomenon, tolerating many jokers on the way, in the process. This is a dynamic aspect of science. Several aspects of science need not confuse anybody just like a man who can be seen from different angles at the same time but without any loss to his basic entity : physiological, psychological, sociological economic, regional and global. He is also a man, citizen, father, uncle and grandfather etc. In this context, let us now reflect incompletely over the nature of our universe and the shape of earth.

Since times immemorial, man has been curious about his environment, both physical and nonphysical. Man has been trying hard to understand his World and offer explanations of varying degrees of acceptance. In his failures, he has not hesitated to personify natural forces like air, water, sun and wind etc. and seek mythological support through sacrifice of humans, animals and materials, self-restraint and rituals. To quote Frazer in the Golden Bough :

> The ceremonies connected with sowing last several weeks, and during this time certain taboos have to be observed by the people. Thus, on the first day of the festival, the whole population, except the very old and the very young, must

> refrain from bathing: after that there follows a period of rest for eight nights during which the people may neither work nor hold intercourse with their neighbours. On the tenth day, the prohibition to bathe is again enforced; and during the eight following days the great rice-field of the village, where the real crops are raised, is sowed. The reason for excluding strangers from the village at these times is a religious one. It is fear lest the presence of strangers might frighten the spirit or put them in a bad humour, and so defeat the object of the ceremony, for while the religious ceremonies which accompany the cultivation of the rice differ somewhat from each other in different tribes, the ideas at the bottom of them, we are told, are everywhere the same: the aim always is to appease and propitiate the souls of the rice and the other spirits by sacrifices of all sorts.[11]

We find some of these superstitions in different forms continue to exist even today in our society. At that time, there was no difference between philosophy and science. Learned men, however, did speculate over several diverse problems at the same time. One of the problems that baffled them then was to find out the basic materials out of which things all around were made of; and the shape of the earth. Thus Thales of Miletus (640-546 B.C.) who was extremely dissatisfied with the Egyptian practical fund of knowledge, regarding the construction of pyramids, went himself to the extent of finding general principles and reapplied them to solve practical problems. He applied himself to the problems of geometry of triangle; and successfully computed the distance between the shore and the ship at sea. He successfully predicted the solar eclipse in 585 B.C. He determined solstices, equinoxes, and succeeded to estimate very nearly the apparent diameter of the sun. He believed that water was the basis of all things. He imagined earth as a 'short cylinder or disc floating in water: and upper heavenly hemisphere surrounded by water moved around it. His pupil Anaximender (611-547 B.C.) did not believe that water was the sole basis of all things. He regarded 'Infinite' as the basis of all things'; that is, matter was created from infinite and transformed by the separation of opposites. He imagined earth as a flat disc suspended in the centre of the Universe. Interestingly enough, he regarded other heavenly bodies as spherical. He received support from his pupil, Anaximenes (585-528 B.C) regarding the shape of earth. Like Thales, he argued but reached a different conclusion : air and not water was the basis of all things. He further believed that earth was like a 'flat table floating on air, sun was like a leaf, and the stars had originated from earth and were full of fire. Further, he pictured 'stars as studs attached to a vast crystal'. Then came Pythagoras and his followers who believed that mathematics was the sole basis of our universe. Pythagoras (572-492 B.C) imagined earth and other heavenly bodies as spherical, being perfect geometrical figures. He regarded earth as stationary at the centre of the universe but his followers speculated it as a 'planet in motion'. For Heraclitus (540-475 B.C), world was in a state of flux whose, one of the chief distinguishing features, was changefulness. He summed up his idea in the statement : 'Everything flows'. Empedocles (500-430 B.C) developed all these ideas further and came to the conclusion that the universe comprised four elements, namely, earth, air, fire and water, sharing four primary qualities, namely, moisture and dryness, heat and cold ; and the twin motions : affinity and opposition. He also explained correctly not only eclipses but also the formation of day and night. His contemporary, Anaxogoras (488-428 B.C) believed in the glory of heavens. He further believed firmly that the chief object of being born on this earth was to 'investigate sun, moon and heaven'. He also explained how lunar eclipses occurred. Like the pythagoreans, he believed that the universe was explicable in terms of mathematical principles. In 350 B.C., Eudoxus suggested his own model of the universe—an elaborate and compact system of concentric circles with a stationary earth at the centre : and reproduced on it the motions of earth, sun and moon etc. with the help of twenty-seven spheres which moved within one another. Callipus, later on, improved on this model by suggesting one additional sphere each to Mars, Venus and Mercury.

Let us now come to Aristotle (384-322 B.C) who was supposed to be the master of ail knowledge. It was said of him for several proceeding centuries that a thing could not be true (or exist) if it had not been found in his writings. There is an interesting anecdote to confirm this. Once a medieval student discovered spots in the sun and reported his discovery to his priest. The priest in turn commented : 'My son, I have read Aristotle many times ; and I assure you that there is nothing of the kind mentioned by him.' Go, rest in peace and be certain that the spots which you have seen are in your eyes and not in the sun.' Aristotle suggested his own geocentric model containing fifty five rubbing over each other spheres. Further, each sphere revolved in a circle with a constant speed. Later on, it proved to be an erroneous assumption least doubted by Copernicus in his life time. Aristotle's contemporary, Heraclides of Pontus, suggested a heliocentric model of the universe. It is, therefore, doubtful whether he included in his scheme superior planets as well. Seventy five years later, another giant of Greek astronomical thought, Aristarchus approached the entire problem of solar system geometrically. He calculated the distance between sun and earth, diameter of the moon and the sun-earth-moon angle. He was, remarkably, the first to suggest a heliocentric hypothesis, Archimedes (287-212 B.C.) said of him : 'His hypotheses are that the fixed stars and the sun remain unmoved, that the earth revolves about the sun in the circumference of a circle, the sun lying in the middle of the orbit'. The last great giant in the series was Hipparchus, discoverer of the precession of equinoxies, who made a highly useful catalogue of fixed stars in addition to other work which perished over the years. Now, we come to Ptolemy (90-168), a philosopher, mathematician and geographer. He determined the angle of elevation of the moon and calculated its distance from the earth. He also produced a geographical outline of the known world and subsidiary maps of twenty six regions. He also reproduced globe on a plane surface. He regarded earth not as flat but spherical. It was a mixture of land and sea ; and not surrounded by sea on all sides. He regarded earth fixed at the centre around which heavenly bodies attached to great crystal sphere revolved at constant speed in circles. He further 'attempted to explain deviations in orbits by postulating a subsidiary circular motion of planets, around their own axis'. It appears that it never struck Ptolemy that the planetary orbits could be elliptical. He wrote thirteen books : Great systems of Astronomy, popularly called Almagest when translated into Arabic, later on. Leonardo da Vinci (1452-1519) considered the possibility of sun and not the earth as the centre of the Universe. The idea of Aristotle and Ptolemy held sway until Copernicus came on the scene.

Copernicus (1473-1543) studied at depth the past works of all the preceding philosophers ; and found that the opinion regarding the position of earth was divided. He suspected the utility of concentric circles, eccentrics and epicycles. He was more of a thinker than an efficient star gazer. He, therefore, felt the inner urge to simplify the complex solar system full of so many qualifying clauses and unwarranted assumptions. His radical reorganisation of the solar system supported by observational data, unfortunately, conflicted with his official teachings. Naturally, he did not, wish to be ridiculed by his colleagues and others as well as enter into avoidable controversies. It is interesting to note here that not catholics but the so-called progressives, that is, protestants heaped more abuse on him. Martin Luther who himself spearheaded a big progressive movement, regarded him a big fool who would, 'turn the whole science of astronomy upside down'. He in fact sought the advice of Osiander, a follower of Martin Luther and preacher. He said :

> Astronomical hypothesis should not be taken literally, but only as a helpful means for aiding computations concerning the heavenly bodies...for who could give us sure information as to whether the irregular course of the sun is produced by an epicycle or an eccentric motion, if we followed the hypothesis of Ptolemy, according to which both are possible. Therefore, I should think it very desirable if you contributed something on this question in the preface. Thus you might assuage the Aristotleans and the theologians who, you fear, will contradict you.[12]

An hypothesis need not be true. It should be only useful. Copernicus regarded it as an attempt at compromise with what he believed himself to be true and what others would like to believe, of course, in error. The scientist in him rebelled and cared little to accept conditional advice. Consequently, he did not publish his results. Anyway, Copernicus appears to have argued somewhat as follows :

He first asserted that the Universe is spherical, sphere being the shape of a perfect body requiring no points. Secondly, in this context, earth is also no exception. Thirdly, both the land and water on it form a sphere. Fourthly, the action of a heavenly body is uniform and circular or 'else a combination of circular motions'. He then transferred the motion of the sun to the earth, suggesting to the latter daily as well as orbital motions in the process. He thus provided a simpler explanation than the prevalent one by discarding a mass of epicyclic movements. Further to clinch the issue, he said :

> ......But in the midst of all dwells the sun. For who, in this beautiful temple, could place this lamp in another or better place than that from which it can at the same time illuminate the whole ? Which some not unsuitably call the light of the universe, the soul or the ruler, Trismegistus calls it the visible God, the Electra of Sophocles the all-seeing. So indeed the sun, sitting on the royal throne, steers the revolving family of stars.[12]

Part of the difficulties of Copernicus lay in imagining that the heavenly bodies moved in perfect circles. Anyway, his ideas did not win universal acceptance. He did not alter his ideas to seek acceptance of his contemporaries. On the other hand, he intended to disclose his ideas to the world as perfectly and faithfully as he comprehended them. The publication of his book was not a financial success. The second edition had to await another twenty three years. Instead, it was left to Giordono Bruno (1547-1600) who put the revolutionary ideas of his master as clearly and forcibly as possible. He believed in the essential unity of nature, motion of earth round the sun, and also the motion of the sun itself. He did not regard solar system as the centre of the universe. For him, there were, no longer, fixed points in the constellations. He thus anticipated Einstein in an elementary way when he said, "Bodies can only be said to have certain relations to other bodies or to frontiers that are chosen arbitrarily." It was after all a first step towards the concept of Relative Motion where any object could be imagined to revolve about another object chosen at one's sweet will. Galelio, Kepler and Newton not only popularised his basic ideas but also made original contributions to his model. Man no longer now lives at the centre of the universe. Even our sun is a small star as compared to hundred million stars which exist in our infinite universe. There is not one galaxy but many galaxies. And our universe continues to expand. These are staggering facts. We remember Copernicus not for the 'inaccuracies of his book, but for his vision in pointing the way toward astronomical truth' (David D. Knight). Let us conclude this account in the words of Albert Einstein who talked feelingly of our debts to past philosophers and scientists:

> Many times a day I realize how much my own outer and inner life is built upon the labours of my fellowmen, both living and dead, and how earnestly I must exert myself in order to give in return as much as I have received.

8. From jungle to zoo (The periodic table)

The ancient thinkers saw so much around them. They, therefore, put all sorts of questions which fascinated them. One of them was : What elements compose this universe ? The Greek thinkers located four elements, namely, earth, air, water and fire. According to them, these four elements in varying proportions were the basis of all things which composed this universe. The sacred and the unapproachable heavens had the fifth element, namely, ether. This thinking remained for considerable time. The medieval alchemists notorious for quackery, fakery and magic had the upper hand on Greek because they actually experimented with a variety of substances. They thus gained at first hand lot of knowledge about the properties of various reacting substances. For example, metallic and inflammability properties were attributed to mercury and sulphur. On the basis of their extensive hit and trial experimentation, they somehow came to a fruitful hypothesis (which in fact engaged them in erratic experimentation for several centuries) which favoured transmutation of elements meaning thereby that various new substances could be made provided one could add or substract elements in the right proportion. In this context, they said that they could obtain gold from lead by adding mercury to it. It was a firm faith of the alchemists which brought in its train extensive, undirected and inconceivable experimentation. In this futile search, they discovered more important substances than gold, for example, phosphorus and mineral acids. But still they got rich people interested in their pursuits, for after all, prize was high in this adventure, if successful. Even the wellknown scientists like Newton, engaged themselves in this sort of wild goose experimentation. The result was that atomic weight became the distinguishing property of a given atom. For example, Sulphur atom is heavier than Oxygen atom. Jacob Berzelius, for the first time published atomic weights of some elements on the basis of two standards, namely Oxygen=16 and Hydrogen=1. This system did not catch up with his contemporaries, Again thirty two years later, another Italian chemist, Stanislao Cannizzro developed new precise techniques for determining the atomic weight of known elements.. He arbitrarily took the atomic weight of Oxygen as sixteen. On this scale, the atomic weight of hydrogen came out to be 1.008. In 1914, the American Chemist, Theodore William Richards, got a nobel prize for obtaining very precise values for atomic weights. Atom is now no longer a philosophical concept or a semi-mystic concept. It is something tangible. In 1955, Erwin W. Mucller of Pennsylvania Stale University developed a field ion microscope which, for practically purposes, brought atoms into human view.

Let us now pick up the story of elements again. Like the present day discovery of fundamental particles by physicists, chemists of the nineteenth century found themselves increasingly in a jungle as the number of elements began to increase. Frantic efforts were, therefore, necessary to bring them to a zoo. After all, it is the consuming aim of science to simplify knowledge. Many imaginative and workable hypotheses developed. In 1862 and 1864, a French geologist and a British chemist, namely, Alexandre Emila Beguyer de Chancourtois and John Alexander Newlands, independently suggested that they could arrange elements in a tubular form on the basis of recurrence of similar properties, that is, elements, regardless of atomic weights, could be placed in one column. Their conclusions were ridiculed by their contemporaries. Their work came into print only when Periodic Table, later on, became respectable and fashionable. In 1869, Dimitri Mendeleev finally brought order into the jungle by propounding his powerful Periodic Table. A German chemist Julius Lother Meyer also made more or less the same point. Mendeleev regarded properties of atoms (elements) more important than their weights. For example, tellurium (Atomic weight=127.61) need not come after iodine (Atomic wt.=126.91). Also in the new view, bromine and iodine could become cousins. Mendeleev was careful in his suggested incomplete table, that is, he drew a blank at a place where he could not find elements of suitable properties. He even went to the extent of predicting theoretically the properties of three missing elements, and gave a call for their discovery. All the three elements (hallium, scandium and germanium) as predicted were discovered in 1875, 1879 and 1886 respectively.[13]

9. Our foods

Next to air and water, is food without which a man cannot live for long. The ancient thinkers speculated more on the glory of the heavens and the mathematical basis of this universe than on foods, which went straight into their tummies, undergoing mysterious changes there. For simple living and high thinking or to live a healthy and happy life, the Greeks like some of the Hindu philosophers and saints, recommended moderation in eating. This was no answer to the problem for they knew little about metabolism as well as the essential ingredients of human diet. They could not provide answers to the nutritional problems for biochemistry and modern laboratory tools were to develop after about 2200 years. The thinkers were therefore to advise on foods on the basis of their individual experiences. Thus developed food superstitions which even exist today in one form or another both in the advanced and developing countries. In the middle ages, Santorio Sanctorius did the first nutrition experiment by consuming certain samples of food. He concluded that one pound of food consumed does not give him an extra one pound weight. These were the dominant days of alchemy when alchemists heated odd things to produce gold. His experimentation gave signals to other workers. The first attempt at classification of foods was made by the English physician William Prout who divided foods into three categories, later on, called carbohydrates, proteins and fats. Their properties were determined by Justus van Liebig who found proteins more basic than carbohydrates and fats both put together in human diet. A French man named Renes Reaumur carried interesting experimentation on birds by feeding them on various foods and recovering the same after certain lapse of time. Specifically speaking, he wanted to find out chemical changes occurring during digestion. Lazarro Spallanzani went a step further, at great personal discomfort, by doing the same kind of experimentation on himself. He swallowed thin muslin bags containing bread and meat, and with the help of tied strings, took them out after certain intervals of time. He also intended to study changes occurring during digestion. Their efforts were doomed to failure in the eighteenth century for for them the modern chemistry was yet to be born. Dr, Beaumount, an American army doctor, had a splendid opportunity in his life of examining chemical changes occurring during digestion in a Canadian Furtrapper named Alexix St. Martin hit badly with a bullet. The doctor succeeded to save his life. The doctor fed known samples of food to the Trapper and took them out from the hole left in the stomach. He thus discovered several facts about changes taking place during digestion which he wrote in a book entitled : 'Experiments and Observations on the Gastric Juice and The Physiology of Digestion'. In 1838, Friedrich Woehler successfully synthesized urea without the use of human animal kidney. It was a great triumph for he asserted that the 'philosophy of chemistry must draw the conclusions that the synthesis of all organic compounds must be looked upon as not merely probable but as certain of ultimate achievement'. He further added that sooner or later, it was the turn of synthesizing sugar, salicin, and morphine.

Other investigators of the past centuries raised several problems and attempted to answer them if they could. In science, the very formulation of sharp problems is very important. The French physiologist Francois Magendie showed that dogs fed strictly on gelatine lost weight and ultimately died. In 1854, Bennet Laws and Joseph Henry carried out for the first time nitrogen balance experiments and showed that pigs when fed two forms of proteins 'retained much more of the nitrogen in barley than that of in lentils'. A growing organism gradually accumulates nitrogen from the food it indigests. They further discovered that gelatine is a simple protein deficient in amino acid: tryptophan. So in the closing decade of the nineteenth century, attempts were made to supplement gelatine by adding aminoacids from other proteins. In 1906, the two English biochemists Frederick Gowland Hopkines and E.G. Willocock fed mice on Zein, a protein obtained from corn. The mice died in 14 days. On the addition of tryptophan (an amino acid), they survived twice as long. Their hard evidence favoured the hypothesis that amino acids rather than proteins were more essential component of diet than proteins alone. Mice still died because no one at that time had heard of vitamins. In 1930, the American nutritionist, William C. Rose went to the heart of the problem on amino acids and established, later on, that rats need 10 amino acids in their diet. In 1949, he announced that the paragan of all animals, that is, man needs only eight amino acids. This showed that rat was more complicated and specialized in its amino acid requirements than man. Let us cut the story here and emphasize only that scientifically established blue print of food is essential so that different persons doing different kinds of work do not suffer from malnutrition due to ignorance. The science of biochemistry must provide answers to the following questions :

(a) What are the rich sources of various constituents of human foods ?
(b) What are the essential requirements tangible as well as intangible of human diet ?
(c) What happens to the various constituents of food on eating ?
(d) Can we judge scientifically the effectiveness of a given diet in all its varied aspects for a given individual ?
(e) Is it possible to synthesize human food from the cheapest molecules ?

The story of vitamins

Let us now tell, in brief, the story of Vitamins. People in the distant past had some horrifying experiences with scurvy, a disease which made man weak, gums bleed, teeth loose and wounds difficult to heal. It was, particularly speaking, manifesting itself either in besieged cities as well as on long voyages at sea. In the winter of 1536 in Canada, about one hundred and ten members of Jacques Cartier's crews were struck with scurvy. The native Indians possibly knew the remedy and suggested them to drink water in which pine needles had been soaked for some time. They did not believe it but they did get rid of scurvy. The disease was so terrible that sailors at sea died more of this disease than due to guns and storms put together. Two centuries later, a thoughtful Scottish physician encountered the some problem among the crews aboard the ship Salisbury. He is remembered even today for he conquered one of the most dreadful diseases in medical history. The story of nutrition almost begins with Dr. Lind who, while on the Salisbury, saw symptoms of scurvy among his several crews. Was he then to try one medicine after the other to cure this disease? He did not follow this procedure. He was a voracious reader and, therefore, read all about it right upto the biblical times. Job therein had said, "By the great force of my disease is my skin changed : it bindeth me about as the collar of my coat—my skin is black upon me and my bones are burned with heat." He planned a series of control experiments full of imagination in which he used fresh fruits and vegetables etc. To quote Lind :

> On the twentieth of May, 1747, I selected twelve patients in scurvy on board the Salisbury at sea......Their cases were as similiar as I could have them. They all lay together in one place, being a proper apartment for the sick in the forehold; and had one diet common to all, viz. water gruel sweetened with sugar in the morning, fresh mutton broth often times for dinner, at other times light pudding, boiled biscuit with sugar etc ; and for supper barley with raisins, rice, and currants, sage and wine or the like......
>
> The consequence was that the most sudden and visible good effects were perceived from the use of oranges and lemons ; one of those who had taken them being at the end of six days fit for duty. The spots were not at the same time quite off his body ; nor his gums sound, but without any other medicine he become quite healthy before we came into Plymouth. The other was the best recovered of any in his condition, and being deemed pretty well, was appointed nurse to the rest of the sick.[14]

He had experimented with not less than six different diet supplements in his experimental groups. He wrote a Treatise on Scurvy, later on. But no body believed that such a dreadful disease could be cured by so simple a remedy. He found it a difficult job to convince the high position holding officials to order to give all crews a daily drink of lemon juice. Interestingly enough, Captain James Cook got a gold medal not for circumnavigating the world but for protecting all his crews from scurvy with a daily dose of lemon juice as suggested by Dr. Lind. It is only after his death that the British navy accepted his advice and the dreadful disease disappeared among navy crews now popularly called 'Limeys'. But nobody knew how lemon juice cured scurvy or whether it was a vitamin deficiency disease. Even in the last century, the biologists refused to believe that intentional food factors could cure diseases in the face of Pasteur's Germ Theory of Diseases.

Let us continue with this story but with Japanese naval doctor named Takaki. Beriberi, another vitamin deficiency disease, raged badly on the spotless ships of the Japanese navy. It first paralysed its victims and then killed them. Dr. Takaki studied this problem on the basis of some observed interesting facts. The villages were completely free from this disease but its incidence was increasing in cities. This terrible disease only occurred among rice eating populace. He attributed this to the form of rice the villagers and the city people ate. He, therefore, hypothesized that white polished rice lacked something which caused this disease. He approached, in vain, the senior officers to test this hypothesis with an experiment which was, of course, very costly. In the mean time, the beriberi continued to kill the sailors in large numbers. The authorities then reclined. Dr. Kakaki suggested the following experiment :

> Let the sailors on one ship eat the diet common on British ships, their meat, fish, vegetables, bread and canned milk. And let the sailors on the second ship have our standard ration of rice. "Are you suggesting there is something wrong with our rice ?" the doctor was asked. "You must know we provide the very best rice for our navy. Not the cheap brown rice that village people eat, but fine white rice that keeps well and does not rot, Oh, no, this is a foolish idea.[14]

Two ships, now become historical, were used viz. Ruijo and Tsukaba. They carried 276 men each, followed the same course, visited the same number of ports and returned after more or less the same time. The results were startling. In the experimental ship, only fourteen suffered from beriberi who had eaten rice secretly, and in the control one, twenty six sailors died and another 169 cases suffered from beriberi. No body took him and his explanation seriously but he succeeded like Dr. Lind to save many lives from beriberi. Now another Dutch surgeon in Java came on the scene. Beriberi there baffled this young doctor named Christian Eijkman for he could not see with his own eyes the consequent human misery. Least expectedly, he found that whatever had been taught in medical science relevant to the theory of disease contradicted his first hand experience in the East. His experience was more or less similar to Dr. Kakaki. Beriberi was conspicuous by its absence in villages not under Dutch control. But it claimed its victims in those villages which enjoyed first class sanitary measures under the control of the enlightened Dutch. It should not be lost sight of that he lived in those times when the germ theory of disease as propounded by L. Pasteur and Robert Kock reigned. He found himself unequal to the task, professionally speaking. He was bitten by mosquitoes there, suffered from malaria, returned home and, later on, studied under Dr. Robert Kock. In the meantime, the beriberi was raging badly in areas under Dutch control in the West Indies. The Dutch government appointed a commission of senior scientists to tackle this problem. They approached Dr. Robert Kock, the chief expert of germs, to accompany them to Java, at least, on humanitarian grounds. Dr. Robert Kock did not have time and so, as good luck would have it, suggested the name of Christian Eijkman. The members of the commission found a beriberi microbe in the blood of a beriberi victim, congratulated themselves on this discovery, ordered to tighten sanitary measures and suggested the preparation of a vaccine in due course of time. They returned home except Eijkman who perhaps was to do the follow up work. Like Dr. Lind and Dr. Kakaki, he persistently put himself several questions. A well formulated investigative question suggests its own line of inquiry. The difficulties for the investigator increase when past experience or prevailing notion suspects seriously the futility of the new line of attack right at the moment of taking the first step. He asked a very simple question : why were remote backward villages free from beriberi ? Why cleanliness did not help much in reducing the incidence of this disease ? It was the pursuit of these questions which won him nobel prize, later on. Despite some disbeliefs, he again started where the commission had left off except that the experimental material was different. He injected some blood of the beriberi victim in some healthy hens available easily in his prison compound. Nothing happened for some time. He felt extremely happy when he noticed some wobbling with a strange unnatural gait among those he had injected blood. He was disturbed badly when others uninjected hens also showed symptoms of wobbling. After some time, these symptoms again disappeared. It was a confusing experiment. Spending more time on the microscope did not help much. While still confused, he found the reasons when he chatted with the official cook. The earlier cook was feeding white rice ; and he himself under strict orders was feeding hens the dirty brown rice.

This information helped the doctor to induce and cure this disease at will. The hypothesized beriberi microbe was thus of no significance. But still, no body believed in him for he was accusing the neat and highly polished rice of causing untold human misery. At the same time, he had to face another inconvenient fact disclosed to him by another doctor. In a particular isolated monestry, where monks and nuns lived together under more or less the same identical conditions, beriberi only claimed nuns as its victims but never the monks. Why ? On further analysis of this nothing short of nervous situation to Dr. Eijkman, it turned out that the nuns being quite fussy about extra kitchen cleanliness washed their brown rice not only repeatedly but also scrubbingly until 'it lost every trace of its natural coathing'. The monks, comparatively speaking, were quite carefree in this respect. He wrote his first paper in Dutch in 1890. For twelve years, his work remained unknown to the American Army Medical Corps. In 1898, the American officers encountered the same earlier experiences and facts of Dr. Kakaki and Eijkman in Philippines after the Spanish American war. For example, the Americans were horrified when they saw prisoners at the Bilid prison eating dirty brown rice containing many impurities. They not only switched to white rice but also got the prison scrubbed spotless. The result was the appearance of beriberi. Disease gradually disappeared when they switched to the original form of ration. It is now interesting to note that Dr. Eijkman did dot seriously trust his original discovery. For several years, he believed in a mysterious poison which caused beriberi and was counteracted by some mysterious agent present by chance in brown rice.

What was happening ? Certain mysterious additional food factors which control vital functions of human body lay hidden to be discovered. But the paths of discovery were highly difficult. The experimenters tried experiments on rats, pigs, pigeons, cows and other animals to find the truth. Sometimes conflicting results came. The lack of Vitamin C caused scurvy in man and pigs but not in rats. It later came out that rats have the inherent ability to manufacture their Vitamin C requirements within their bodies. Fishermen in Norway and Newfoundland suffered from night blindness which disappeared quickly if they ate the liver of fish. Earlier, the Swiss experimenters had found that mice died when fed on chemically purified known ingredients of milk. In Paris, the biochemists obtained carotene from a dried spinach which had been kept in the museum for 32 years, and fed to certain rats (suffering from an acute deficiency of Vitamin A) who recovered immediately. The biochemists all over the world were in hot race for finding not only the various sources of vitamins but also preparing them from different sources with a view ultimately to study their chemical structure. It should not be forgotten that these additional food factors existed in minute amounts. For example, a ton of rice was found to contain about 5 grams of Vitamin B. Interestingly, Berbart McLean Evanes and K.J. Scott in 1922 suspected a vitamin as causal factor for insterility in animals. It cannot be concluded or extrapolated from this that the natural sterility arises this way. It is this way that the science progresses ahead.

The scientific pursuit has to be intensive as well as extensive otherwise it suffers from both short-sightedness and far-sightedness. Human body also needs minerals for its effective functioning. Iodine and iron deficiencies are known to most of us. The start in this direction was given by a Swedish chemist in the mid eighteenth century that bones largely contained calcium phosphate. V. Menghini showed that blood contained iron. By the mid nineteenth century, the list was extend-ed and included calcium, phosphorus, sodium, potassium, chlorine, magnesium and iron. In 1882, the English physician Sidney Ringer found that a frog's heart could be kept working outside its body by putting it in a solution called the Ringer's solution which contained sodium, potassium and calcium in proportion as found in frog's blood. Lastly, it was found that elements essential to life were : iron, zinc, copper, manganese, cobalt, molybdenum ; and their absence caused corresponding deficiency diseases. In 1896, a German biochemist found that the thyroid conspicuously contained iodine. Nine years later, David Marine hypothesized that the growth of the thyroid was due to the deficiency of iodine. For ten years, he experimented on animals and goitre patients by giving various iodine containing compounds. People protested when he suggested the iodination of water and table salt in those areas where goitre was prominent. It took him another ten years to make them generally acceptable. In our times, the same controversy arose when it came to the fluoridation of water which checked tooth decay. Is tooth cavity inside the mouth less important than disfigurement by goitre ? It should not be forgotten that fluorine is poisonous but scientific evidence established that one part per million of fluorine in water was sufficient not only not to mottle teeth but also to prevent tooth decay later on. It can do the trick only during childhood when the teeth are still developing. To quote Issac Asimov :

> The dental profession is now convinced, on the basis of quarter of a century of research, that for a few pennies per person per year, tooth decay be reduced by about two thirds with a saving of, at least a billion of dollars a year in dental costs and a relief of pain and dental handicaps that cannot be measured in money. The nation's dental and medical organizations, the United States Public Health Service ; and State Health Agencies, recommended fluoridation of public water supplies. And yet, in the realm of politics, fluoridation has lost a majority of battles. More than 100 communities, totalling some 22 million people, have fluoridated water. But a group called the National Committee Against Fluoridation has aroused community after community to write down fluoridation and even to repel it in some localities where it had been adopted.
>
> Two chief arguments have been employed, by the opponents with the greatest effect. One is that fluorine compounds are

> poisonous so they are but not in the doses used for fluoridation. The other is compulsory medication, infringing the individual's freedom. That may be so, but it is questionable whether the individual in any society should have the freedom to expose others to preventable sickness. If compulsory medication is evil, then we have a quarrel not only with the fluoridation but also with chlorination, iodination including vaccination against small-pox, that are compulsory in most civilized countries.[14]

This means that scientific facts objectively obtained do not become straightaway acceptable to the lay public. They have to be made emotionally satisfying as well. The same sort of controversy was spearheaded in this country by our respected Raja Ji (Formerly Governor General of India and the Chief Minister of Madras) on B.C.G. A furore arose in U.P. when a Minister there stated in the assembly that scientific evidence has indicated that proteins obtained from rats were not only, comparatively speaking, more nutritious but also more tasty as well. The same sort of problem arose on the colouring of Dalda ghee. We have yet to accept Soyabeans despite their high nutritious value as a common article of diet even among the affluents. Suggesting simple and cheap foods for healthy growth is a scientific problem, but change of food habit is a much more complex problem.[14]

10. The origin of life

Man is and has always been curious about the environment in which he lives. Like children, he puts all sorts of questions to himself and his fellow brothers. Unlike children, he does not give up seeking answers whatever may be the odds for he seeks to satisfy his age old curiosity by supplying sensible answers or explanations. These sensible answers are as good as they can be. It hardly matters if the given answer turns out to be wrong for a wrong answer (or even partial one) to a complex question is far better than no answer at all. It is then more likely either to be improved upon sooner or later or to be demolished like role of phlogiston in heat, Vitamin F (which turned out to be no vitamin at all), ether, vital force, sun or earth at the centre of the universe or searching suitable dye for dalda ghee in our times. One of such questions that stirred the imagination of man in the past was the origin of life on this earth. Despite explosion in scientific knowledge in our times, we still do not know positively how life originated on earth. Let us now relate part of this story.

In the book of Genesis, there is a direct reference to the act of supernatural creation. Plants and animals were all made by God. All this happened at the command of God. It is, therefore, quite possible that the formation of life was hardly thought of a worthwhile problem, because whatever could not be explained was supposed to be a sacred territory beyond the sphere of human reasoning. There were, however, some curious men who by direct observation believed that frogs came from mud, and insects and worms from decaying matter. Here is an interesting recipe as sure as day light for getting a swarm of bees :

> Take a bullock, kill him with a knock on head, bury him under the ground in a standing position with his horns sticking out. Leave him there for a month, then saw off his horns, and out will fly your swarms of bees.[15]

The English naturalist Ross asserted, "To question that beetles and wasps were generated in cow dung is to question reason, sense and experience". 'Does not mud of Niles produce lot of mice'? As this general observation reported additional cases, a general belief, which continued right upto the end of the middle ages, became acceptable that, 'life arises continually from non living matter'. It is again of interest to mention here that Jan van Helmont, one of the very well-known and highly respected scientists of the seventeenth century, left an interesting method of making mice : 'Take slightly soiled shirts, place them on a dim, quiet corner, sprinkle with kernels of wheat and in twenty one days one would have mice'. It should not be forgotten that it turned out to be as sure a method for making mice as the demonstration of, say, properties of the carbon-dioxide gas. The belief was so strong in Spontaneous Generation that it received little challenge. Perhaps all of them believed in Aristotle who had said that all moist things possibly produce animals. It is no wonder then that Thomas Aquinas, William Harvey and Issac Newton and their other contemporaries believed in spontaneous generation.

In 1668, Francesco Redi was the first person who challenged this assumption. He took several jars in which he put meat of different animals like raw and cooked flesh of ox, deer, buffalo, lion, tiger, dog, lamb, kid, rabbit, duck, geese, swallows, sword fish, and even snakes. He covered some of them with fine gauze and others, he kept open. Through a series of control experiments, he found that maggots grew in the open jars. No such growth was seen in the covered jars where meat decayed and purefied. This classical experiment in way rang death knell of the Theory of Spontaneous Generation. At about the same item, Leeuwenhoek recorded another surprising observation. He ground his own short focus lens and had a very close look at the decaying and putrefying meat. Like Columbus, he discovered a new continent of microorganisms. They were too small in size to be seen by the naked eye. However, they were visible in abundance under the newly discovered self made device called microscope. If one removed them in the covered jars, they, however, soon returned there in large numbers. This meant that whereas maggots and mice did not arise by spontaneous generation, these newly discovered microbes definitely did. In 1745, Needham, a member of the Royal Society, on the basis of his work, supported spontaneous generation. His work became famous after Buffon systematically treated it in which he again supported the theory of spontaneous generation by hypothesizing the existence of organic molecules which ultimately led to the emergence of life. Charles Bonnet (1720-93) fiercely opposed Buffon and presumed the existence of germs. The contest was lively and hence free speculation on rival systems among the ordinary people. In 1765, an other Italian priest, Lazzaro spallanzani (1729-99), performed an other experiment. This experiment refuted not only the claims of Needham and Buffon but also denied the spontaneous generation of microbes as well. He took a retort type of flask, put some soup into it, boiled it for some time and then sealed off its neck. The soup prepared in this manner did not spoil for a long time. No microbes were seen inside it as well. Again it was a decisive experiment which was challenged by Tuberville Needham. Francois Appert did not waste time in this controversy. Instead, he found it a fine way to preserve soup ; and used this original piece of discovery to found canning industry in France for which he got a medal from the French Academy of Sciences.

The proponents of the spontaneous generation were not convinced by this experiment at all. They, in fact, explained it away by suggesting that some sort of vital principle was involved in it which was susceptible to destruction by too much heating and boiling. This is why that microbes did not turn up in Lazzaro spallanzani's flask. The controversy generated heat without light on both sides. It was now the turn of Louis Pasteur, a great French chemist. He was advised by Biot and Dumas not to waste too much time on this problem for the inherent difficulties in the solution of this problem were too many and too complex. He was even advised by them to drop this problem. He tested several hypotheses ; and through his neat and clean experimentation demolished the theory of spontaneous generation. He also rejected the vital principle hypothesis as propounded earlier. He again came into conflict with Pouchet, and Roven : his contemporaries and countrymen. The latter collected evidence which favoured the theory of spontaneous generation. It is of interest to mention that both believed that boiling water kills all sorts of living organisms. They also believed that there is no difference in the choice of their experimental materials, namely, sugared Yeast water and hay infusion. Pasteur believed that only the 'presence or absence of microorganisms in the entering air would affect the subsequent development of microorganisms in the flasks whereas Ponchet considered the role of presence or absence of Oxygen very critical'. The controversy was so fierce that the French Academy of Sciences even offered a prize to any one who could solve this riddle by 'well conceived experiments to throw new light, on the question of spontaneous generation'. This resulting exercise favoured Pasteur in the end in the sense that Pouchet and his co-workers ceased to dog the issue still further. It is not rarely that the scientists go beyond the experimental finding to provide a Yes or No answer to a highly baffling question on the basis of logical deduction in the context of the grand working hypothesis in the phraseology of J.B. Conant. It is then the opportunity to develop new concepts and new modes of experimentation for tidying up the mess as clearly as possible.

The fundamental question still remained : If spontaneous Generation Theory is wrong, then How did Life Originate on Earth ? Let us now attempt to close this issue. It appears that life originated with spontaneous generation on this earth. Lucretius in his poem on The Nature of the Universe says :

> The name Mother was rightly bestowed upon the earth, since she brought forth the human race, and gave birth at the appointed season to the beasts that run wild in the hills, and to the birds of the air in all their rich variety. Then, because there must be an end to such parturition, the earth ceased to bear, like a woman worn out with age.[17]

This is not a respectable scientific argument. Towards the close of the nineteenth century, some theoretical thinkers went to the other extreme by suggesting that life was eternal. Arrhenius, the discoverer of ionization, hypothesized that life had always existed. It some how travelled across space continually, leaving the mother planet behind in the form of spores under the impact of light as well as random movement. It was an attractive theory which was rejected, later on, by the discovery of ultraviolet light which killed the bacterial spores. Secondly, there were other destroyers on their way to earth, namely, cosmic rays, solar X-rays, and zones of charged particles. Speculation is not barred if we hypothesize that life some how did originate from organic molecules for about 99 per cent of any living organism is made up of hydrogen, oxygen, carbon and nitrogen. Even charles Darwin speculated on the origin of life from inorganic sources. To quote Darwin :

> It is often said that all the conditions for the first production of a living organism are now present which could ever have been present, but if, (and oh what a big if :) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not be the case before living creatures were found.

In 1924, the Russian biochemist A.I. Oprian in his book : 'The Origin of Life' dealt with this problem exhaustively from a materialistic viewpoint. In 1929, J B.S. Haldane speculated more or less in the same manner though 'transposing the scene from the pond to the sea'. Both Haldane and Oprian 'looked to a long, slow accumulation in the sea of organic molecules, formed by a variety of geochemical processes, in a primitive atmosphere that virtually lacked Oxygen'. The basic problem then is to determine the chance and time required for such a possibility to occur. In 1951, Malvin Calvin (Investigator of Photosynthesis) performed an interesting experiment by passing his energy radiation through a mixture of water, carbon-dioxide and hydrogen. He succeeded to get complex molecules. A little later, Stanley Miller passed a continuing electric spark through a mixture of ammonia, hydrogen and methane for about a week. Using chromatography paper technique for analysing the resulting products formed, he found twenty-five amino acids among which there were few which are the constituents of proteins known to be the part of a living cell. Philip Aberson went a step further by using twenty-five different mixtures of gases containing at least the following four basic elements of organic compounds, namely, carbon, hydrogen, nitrogen and oxygen. He achieved more or less the same results, that is, amino acids and complex organic molecules. This suggests that chemical evolution preceded life evolution. What about the time span of the chemical evolution ? Here also, we are in a difficulty even for a rough guess. Secondly, it is also known that organic molecules perish soon. They rot within a few days in the presence of living organisms for which there is no evidence that they did exist at that time. Even the atmospheric oxygen oxidizes these molecules. How to explain all these things ? The geologists have pointed out that in the early days of our earth's formation, the atmosphere lacked free Oxygen. Let us stop our story and conclude in the words of George Wald :

> To return to our problem, the view currently held is that over vast reaches of time organic molecules, synthesized by a variety of geological processes, accumulated in the oceans, until the oceans became a vast cosmic soup, in which these molecules were preserved under the conditions we associate

with efficient canning : sterility (lack of microorganisms) and lack of oxygen. Here, these molecules achieved higher and higher concentrations, and, in reacting with one another, greater and greater variety and size. Large organic molecules are characteristically sticky, and on colliding readily form aggregates. Oprian has suggested that natural selection, the driving force of evolution, began at this level; for some of the aggregates of molecules, through fortuitous advantages of composition or arrangement were probably better than others at sweeping up organic molecules from the sea about them. These would then grow at the expense of the others. It is thought that some time, somewhere, or perhaps at several times, in several places, such an aggregate of organic molecules reached the stage that an experienced biologist, had one been present, might have considered to be living.

The main point of such an argument as this is to bring this strange and rare event, the origin of life; within the order of nature : that is, to make it an event that must happen, given enough time, wherever conditions exist that make it possible. What are those conditions ? I think that if one faces this question responsibly, one must conclude that those conditions may depart in either direction from those we find upon this planet, yet not too far in either direction and still be compatible with life. That is, I think that for life to exist at all demands a planet somewhat like this earth of about the same size, at about the same temperature and receiving about the same amount and quality of radiation from its sun. How many such planets exist ? One cannot say with any great assurance. Yet the lowest estimate, I have seen, says that at least one million such planets exist in our galaxy alone ; and since there are about 100 million such galaxies visible with our most powerful telescope, a conservative estimate would say that there are perhaps 100 million such planets in the already observed universe. I think it is the meaning of our story that in all such places life can occur. I can see no escape from the conclusion that in many of these places, in which sufficient time has elapsed life has occurred, and has then undergone an evolution much as it has done here, for evolution also is part of the order of nature. This seems to me to be the most important outcome of our story : Life has a status in the physical universe It is part of the order of nature. It has a high place in that order since it probably represents the most complex state of organization that matter has achieved in our universe. We on this planet have an especially proud place as men ; for in us as men matter has begun to contemplate itself, and to ask such questions as this we have asked today.[15]

11. The emergence of electron

Let us trace, broadly speaking, the history of experimental and theoretical developments which gave us some vague ideas of the difficulties met in formulating a fruitful model of electron on the basis of old and new observations made across the time span of several hundred centuries. And how the curious men ultimately succeeded in smashing the walls of the philosophical atoms postulated to be the tiniest particles composing matter including ourselves. Background work for the same had been done by some men of antiquity who had identified electrical phenomena in four unrelated ways. Now consider the personalities : Greek philosophers like Plato, Epicurus, Roman poet Lucretius, Pultarch, St. Augustine, Jerome Cardan, Gilbert, Niccolo Cabeo, Newton, Gray, Dufay, Coloumb, Galayani, Volta, Oersted, Ampere, Seebeck, F.G. Ohm and Faraday. Faraday discovered electromagnetic induction and laws of electrolysis in 1831 and 1832. This is a vast stretch of time in which through ridiculous hit and trial as well as disciplined speculation, the curious men through the ages have tried hard and arrive at the evasive truth. Let us now again relate a part of this story.

It is of interest to mention that the ancients knew of electrical phenomena, for example, lightening, torpedo fish in the process of kill, St. Elmo's fire and attraction by amber of small objects when rubbed. They did not try to interrelate them but considered them as four independent phenomena. Plato in one of his dialogues referred to the effects of rubbed amber and regarded them as having some mysterious relation with each other. The explanation offered to explain this behaviour at that time was that on rubbing, amber acquired a fascination, longing or need for the small pieces, some sort of foodstuffs for it. Epicurus, Lucretius, and Pultarch imagined that a magnet attracts iron because it emits strong exhalations as a result of which the surrounding air pushes the iron piece to the magnet. Pultarch further attributed to amber effect a flameous and spiritous nature. He was careful to note that whereas magnet attracts iron, rubbed amber attracts all sorts of small pieces. The description of these interesting effects appeared in The City of God of St. Augustine in 428. He asked his audience to distinguish carefully between verifiable and unverifiable knowledge. A magnet attracts iron but does not attract straw. The reason is not known. Then he adds, 'If such phenomena were inexplicable, he asked, why should it be demanded of man that he explain miracles by human reason'? It was a distinguishing feature of medieval schools as well as scholars that they encouraged 'strong respect for law, willingness to think in general terms, habits of orderly thought, and a feeling for the existence of order in religious matters, if not secular'. J. Cardan in 1550 summarized the evidence of his predecessors and concluded that magnet and amber do not attract in the same manner. Secondly, a rubbed amber emits a 'fatty and glutinous humour' which on absorption by the small pieces of different materials attracts them towards itself.

William Gilbert (1544-1603) made several observations (especially with his self-designed electroscope) and gave a serious thought to explain the interesting observations. Scientific methodology, for the first time, thus arose out of his own extensive experimentation. He read past knowledge available on this subject and came to the conclusion that the whole crowd of past philosophers, practically speaking, has contributed nothing to the study of this subject. Then he described his experimentation. First, he found that there were other substances like diamonds, sapphire, carbuncle, iris gem, opal, beryl, rock crystal, sulphur, hard sealing wax, and hard resin which behave like amber in varying degrees. He called them electrics. Further, they attracted all metals, wood, leaves, stones, earth, water and oil. In the process, he clarified many concepts. He, for example, showed that attraction results only after amber has been sufficiently rubbed to produce warmth. He contradicted the existence of any fatty humour as attributed by J Cardan earlier. Instead, he proposed another term : electrical effluvia for action at a distance was not known at that time. He also contradicted Pultarch that air is at all involved in the attraction business. He saw repulsion but did not observe it. He, therefore, failed to discover this phenomenon. The same is true of electrical conduction because it was excluded of any consideration for he had firm belief in the ability of an object to 'suppress the effluvian at its very start' when it touches the charged electric. It should be remembered that a given hypothesis is double edged. It can suggest new experiments as well inhibit new ones. Cumulatively, they suggest a series of fruitful experiments which lead to the development of broad hypothesis constituting, later on, the conceptual schemes of the resulting body of scientific knowledge. It was not easy to experiment in these days because experimentation was considered beneath the dignity of scholars. Optical illusion was considered far more important than grinding lenses and constructing optical devices like telescopes, microscopes and spectacles. Gilbert and a few others thus heralded new experimental philosophy by closing in the gap between the scholar and the experimenter (including worker), synthesizing in the process, logic and philosophy for the fruitful solution of scientific problems.

Niccolo Cabeo, in turn, added a few more substances to the list of electrics already developed by Gilbert. He observed repulsion and like Pultarch, believed that electric on rubbing emits effluvium which drives the surrounding air. He did not believe in electrical repulsion as such but attributed the same as 'merely the mechanical rebounding of a light object upon colliding with a heavy one'. His hypothesis led to another deduction, namely, that no repulsion would occur in a vacuum. Practically, it was very difficult to test this deduction. The Florentine academicians instead discovered mutual electrical attraction in vacuum by suspending a place of electrified amber in the form of a pendulum and bringing near it a small object. No one gave a thought to this new observation. In 1675, Boyle again attacked this problem and showed that attraction occurs in vacuum as well. He insisted that electrified electric emitted some kind of atoms or particles. It was in the same year that the French Academy of Science had announced the production of barometric light. Scientists at that time attributed this optical phenomena to sulphur or phosporus. Francis Hauksbee, on reading an account of this problem, became curious about it. He studied it in close details and showed that phosphorus or sulphur had nothing to do with this mysterious phenomena. On the other hand, the glass tube became charged due to rubbing by the sloshing of mercury inside it. He then questioned himself to find out any other substances which could produce flashes of light when rubbed in partial vacuum. He found that rubbing was a must in the production of light ; and substances could be used to produce bright light for reading, say, a book or a newspaper at night. Through his extensive experimentation, he found that light is produced in an unrubbed glass globe when another glass globe in its neighbourhood is being electrified. The shape of the globe has nothing to do with it because the light flashed even in an evacuated glass tube. He thus nearly discovered electrification by influence which he described for the first time. But he struck to the Effluvium hypothesis. He thus missed another explanation for this new phenomenon. It is also not known how he explained both attraction and repulsion with his notion of Effluvia. But he linked two effects, namely, amber and barometric. He discovered other effects which he could not explain satisfactorily with the help of the prevailing notions of his days. To quote Francis Hauksbee :

> Now how for his experiment may serve to explain the nature of electricity, magnetism or gravitation of bodies is beyond my sphere to determine, but with all humility, I submit to these learned gentlemen of this honourable society who have treated on these subjects.[16]

Stephen Gray (1666 or 67-1736) hypothesized that an object gets electrified when it touches an electrified body. He then tried to find out whether electrification could be transferred from one body to another body in the absence of any physical contact. He thus discovered electrification by influence in which the notion of effluvia played little role. He also showed that hand and other parts of our body are good conductors of electricity. In collaboration with Godfrey and Granville Wheeler, he succeeded to transmit electricity along a wire 650 ft. long. It is of interest to mention here that he used glass tubes and canes rather than electric generators. Secondly, the phenomenon of electrical conduction was discovered with the help of poor conductors which behaved like good conductors in a humid atmosphere. Thirdly, he succeeded in arriving at the correct limited hypothesis by deducing it from a wrong broad hypothesis, that is, the flow of electric virtue is restricted by the fineness of the carrying cord rather than the material of which the cord is made. On later experimentation, he corrected this error.

Influenced by the work of Gray and Hauksbee, Dufay (1698-1739) also carried out intensive experimentation in France. He found that it is possible to electrify several substances if they are heated first before they are rubbed with any sort of cloth. He also studied electrification by influence and found that the poor electrics exhibit comparatively speaking more electrification than the good electrics when an electrified glass rod or any other electrical is brought near them. He also succeeded to transmit electricity over a 1256 ft. long wire. He further postulated that there are two kinds of electrifications in order to explain unexpected results. He speculated over the nature of matter and electricity. For explaining the phenomenon of electrical repulsion, he attributed a self repulsive property to the effluviums. Demand for popular lectures on electrical phenomenon increased in Germany. The German scientists, therefore, began to take keen interest in this phenomenon. They not only built their own electric generators but also devised original experiments. C.A. Hausen in 1743 designed his own generator and passed sparks between his fingers and body. G.B. Bose set up an ingenious experiment in which it was difficult to kiss the hands of a pretty lady. He produced flashes of light in partially evacuated vessels which 'flowed, and turned, and wandered and flasked' like the familiar Northern lights. There was a belief in those days that the electric charge does evaporate. He devised a condenser which was nothing but a bottle with a nail in which any liquid could be used as the variable. He found that electric shock is a terrible experience which 'stuns arms and shoulders'. He drew sparks from this condenser. On the basis of these observations, he hypothesized that there was animal electricity in the body. In 1746, Musschenbrock contradicted him on his notion of animal electricity by showing that human body was a conductor of electricity. He drew sparks from the condenser on the table. This condenser, is now well-known as Leyden Jar.

During experimentation, scientists consider several pretty mental models before they finally choose one likely to be quite profitable. Benjamin Franklin (1706-1790) was one such great man of science who along with his son collected electricity from the lightning clouds through his world known Kite feat. He initiated new experimentation in electrical phenomenon. Being ignorant of Dufay's work, he developed his own concepts for the new phenomena and firmly believed in one fluid theory. With its help, he not only explained the working of the Leyden Jar but also developed mathematical terminology suggesting, in the process, the possibility of measurement of electricity. He further hypothesized that the amount of electricity in an insulated body remains constant. It was a clear cut statement on the conservation of electric charge, that is, electricity cannot be created or destroyed. He further showed that electrical fluid agrees fairly well with lightning in the following ways: 'giving light, colour of the light, crooked direction, swift motion, being conducted by metals, crack or noise in exploding, subsisting in water or ice, electrifies bodies it passes through, destroying animals, melting metals, firing inflammable substances, and sulfurous smell'. He further found that electrical fluid is attracted by points. On this observation, he hypothesized that lighting should also share this property. He suggested a Sentry Box Experiment which was performed successfully in France in 1752. He, however, failed to explain electrical repulsion with the help of his one fluid theory. About then ten years later, Fran U.T. Aepinus saved the one fluid theory by suggesting that 'particles of ordinary matter attract each other'. In 1760, David Bernoulli proved inverse square law which received support by Priestley, a few years later. In 1785, Coloumb determined experimentally his famous laws of electrostatic forces.

In 1791, Galvani accidentally found that the muscles of the frog's legs would twitch when touched by a pair of dissimilar metals as well as when sparks from a near by electric generator fell on them. He attributed this phenomena to animal electricity because he thought that animal tissue was necessary for the flow of electricity. In 1800, Volta contradicted Galvani on the existence of animal electricity as such because he succeeded to produce large potential differences by dispensing away with animal tissues as such. He used paper or cloth, weak acids and piles of metal discs. In 1801, storage cells, that is, reversible voltaic cells were also invented. This led to the discovery of the heating effect of electric current. In 1802, arc light was built for the first time. In 1819, Oersted found that a magnetic field surrounds the electric wire carrying current. In 1820, Ampere, Biot and Savart determined quantitatively forces acting on a current carrying wire. In 1821, Seebeck discovered the thermoelectric effect. In 1827, G.R. Ohm discovered his famous law. In 1882, Faraday stated the laws of electrolysis. He hypothesized that his results could be understood only in terms of a 'granular or atomic model of electricity'. At about the same time, he had also discovered electromagnetic induction.

Let us now refer to the cathode rays. At about the beginning of the eighteenth century, it had been wellknown that sparks would jump longer in partial vacuum than in air at normal pressure. In 1748, Watson produced 'arch of lamebent flame' in a glass tube of rarified air. In 1838, Faraday produced a long column of purple glow extending from anode to nearby cathode in a glass tube containing air at low pressure. He also observed some dark space, now called Faraday dark space. In 1855, Geissler invented a vacuum pump which could produce very low pressures. Plucker (1858), his pupil Hittorf (1869), Goldstein (1871 onwards) and William Crookes (1879) investigated the various properties of the cathode rays. Controversy arose over their nature. Crookes imagined them as a 'torrent of molecules' which acquired negative charge when they struck against cathode. He showed that his model accounted for all the observable characteristics of cathode rays: straight line motion, right angle (to the cathode) emission, curved by magnetic fields, fluorescence inducing and conveying of energy as well as momentum. In 1880, P. G. Tait hypothesized that the light emitted by these fast moving molecules should show Doppler Effect as judged by the shift in spectral lines. No significant shifts were observed which meant that light originated from those molecules which were not after all moving at high speed. Wiedemann, Goldstein and Hertz in Germany had a close look at the same properties of cathode rays. In turn, they suggested that these rays could be some unusual sort of electromagnetic radiation. They compared very carefully the properties of cathode rays with that of light. The latter showed only two exceptions, namely, it was not emitted at right angles from the emitting surface ; and it was not bent by the strongest available magnetic fields at that time. At that time, no body really knew clearly whether Maxwell's equations allowed magnetic deflection of electromagnetic waves. Interestingly enough, two contradictory models were available which agreed fairly well with the known properties of cathode rays. It was a fruitful controversy which initiated brilliant experimentation for clinching this thorny issue either way. Let us consider now the nature of experimentation and the ensuing argumentation.

Goldstein took a tube 90 cm long and obtained pressure equivalent to one hundred thousandth of the normal air pressure. He observed a sharp patch of fluorescence at the other end of the tube. He then reasoned out that it should not have been so if Crookes had been right. His telling argument was that at this obtained pressure, the average mean free path as calculated mathematically was about 6 mms., but the dark space was found as long as 6 cms. Secondly, the cathode rays after passing through the dark space travelled a distance of about 150 times their average mean free path without any collision on the way for which the mathematical probability was 1 in 10^{65}. In another experiment, he also did not observe any Doppler Effect. He, therefore, concluded that his observations only warranted a wave model for these cathode rays. In 1884, Schuster explained the absence of Doppler Effect by suggesting that it was only the stationery molecules in the path of the cathode rays which omitted light. He then found the upper and lower limits for the charge to mass ratio for these rays by bending them from their straight paths with the help of strong magnetic fields. Thus both agreed and disagreed with Crookes in the sense of their being particles in nature but not in the manner of their formation. Some guess is always better than no guess because it can be tested. He pointed out that the charge to mass ratio for this particle was about 10^8 coloumbs per kilogram. Heinrich Hertz, in 1883, totally disagreed with the negative particle model for the cathode rays. He further found out that these rays could be made to penetrate through thin layers of gold, silver, aluminium, alloys of gold or silver with tin, zinc and copper, acid sputtered layers of copper silver and platinum. On the basis of his own extensive experimentation, he supported the electromagnetic model. To quote Hertz :

> The electrostatic and electromagnetic properties of the cathode rays are either nil or very feeble......These cathode rays are electrically indifferent, and amongst known agents, the phenomenon most nearby allied to them is light. The rotation of the plane of polarization of light is the nearest analog to the bending of cathode rays by a magnet.[18]

His student Philip Lenard went a step further by bringing the cathode rays right into the open air by making them pass through the thin layers of aluminium foil of ·00265 cm. thickness. He considered it a sufficient thick wall for the cathode rays. But the cathode rays travelled for about a centimetre in the open air. He then hypothesized that cathode rays by their this behaviour cannot be particles but electromagnetic waves. J.J. Thomson in 1894 attempted to measure the velocity of these cathode rays which was two hundred thousand metres per second. He, therefore, doubted the wave model. In 1895, Jean Ferrin set up an experiment to detect the electric charge carried by these rays and he succeeded. In 1897, Thomson, on the basis of Lenard's data, hypothesized that the cathode rays traversed through the thin tinfoil because they were composed of subatomic particles. The collective evidence of Perrin and Thomson favoured the particle model and led to its general acceptance.

Pieter Zeeman in 1896, tested Hertz's hypothesis that the light waves, electromagnetic in character, were emitted by the hypothetical oscillators associated with molecules or atoms. He wanted to see the influence of the magnetic field on the wavelength of the light emitted by these alleged oscillators. He did not find any unusual effect. But he drew inspiration from Faraday who had, forty or fifty years age, planned a similar experiment and failed to detect anything. He, therefore, thought it worthwhile to put in a little extra effort in the face of initial failure. He thus experimentally detected the broadening of spectral lines which was of the order of 0.15 Aungstrom. Under the influence of a sensitive microscope, it turned out not be broadening but splitting of the central spectral line on either ends. H.A. Lorentz suggested a particle model which led to the postulation of charged particles inside the atom. Larmor went to the extent of predicting erroneously the number of electrons inside the molecule which count he roughly put at 1000 of them. From 1897 onwards, general speculation in the light of the new incoming evidence in regard to the structure and constituents of atoms which, under the impact of new evidence, ceased to be fundamental particles as earlier regarded.

Oweb, Wehnelt, Becquerel and Ewers obtained electrons not only from different sources (cathode rays, Lenard rays, photoelectrons, hot metals, incandescent metals, beta rays from radium and polonium but also used different methods (deflection from electric or magnetic fields, energy from heating effect of beam as well as from accelerating potential, velocity from Lecher wire apparatus, energy from retardation in electric field, and observation of current cut-off when broad beam is bent in variable crossed electric and magnetic fields) to calculate charge to mass ratios. These values differed by a factor of 3 but Thomson asserted the identity of all the particles under investigation. The evidence therefore converged to make electron as one of the constituents of atom.

In 1895, Wilhelm Knoard Rontgen discovered X-rays which had been just missed by Goldstein, Thomson and even Lenard. Within six weeks of their discovery, he determined all their properties. He compared their properties with Lenard rays. He also did not find any noticeable refraction. He also found that X-rays were neither cathode rays nor ultraviolet rays. He, therefore, hypothesized that these were unusual sort of electromagnetic waves, possibly longitudinal in character. Later on, it was found that X-rays had, comparatively speaking, less wavelength than light waves. Shortly after the discovery of X-rays, Sir Oliver lodge hinted at the possibility that part of the results of Lenard could be due to the production of X-rays when cathode rays struck against the thin tinfoil windows. To quote Andrade at the time of Lenard's death in 1947 :

> He (Lenard) was profoundly disappointed not to have discovered the Rontgen rays which he had almost under his hand and would in all probability have found within a year or so of the actual date if Rontgen had not anticipated him. He never used Rontgen's name in referring

> to the rays. He took as a personal affront any inadequate acknowledgement of his work and was incapable of any generosity or even justice towards any one who, in his opinion, failed to appreciate any part of his service to science.[16]

It is of interest to mention how research on cathode rays turned round an unexpected corner and led to new discoveries : X-rays, radio-activity (Becquerel) and canal rays (Goldstein).

Let us now review the nature of electricity within the last two decades of the nineteenth century. Current of electricity was regarded only a flow of ether (Arthur Schuster). Max Planck also did not believe in electron hypothesis. Wiechart regarded electricity as an imaginary entity existing in thought rather than in fact. Lord Kelvin thought of electricity as a continuous fluid. Even J.J. Thomson was not taken seriously when he suggested that cathode ray particles were perhaps the possible constituent of atoms. As early as 1831, Faraday had suggested the possibility of granular structure as working model of electricity for consideration warranting additional experimentation. In 1874, G. Johnstone Stoney, on the basis of Faraday's work on electrolysis, seriously proposed the atomic theory of electricity. He even estimated the value of charge on such particles. Considering the difficulties, both conceptual and experimental involved at that time, his value turned out be one sixteenth of the currently accepted value. His address to the British Association for the Advancement of science was not published in full for another seven years. He received support from Helmholtz who re-emphasized there to consider seriously the tentative hypothesis of Faraday.

Thomson and his students used X-rays to determine electric charge on this hypothetical particle, Townsend (1897), Thomson (1897), H.A. Wilson (1903), Perrin (1908 to 1910) and others attempted to measure electric charge through a variety of methods. Avogadro's number was determined, for example, by fourteen different methods. This facilitated determination of masses and charges of individual ions and electrons. It is of significance to note here that in these measurements; a large number of electrons were involved. It was therefore, still an open question whether all ions in electrolysis carry the same charge, It was definitely an unsurmountable problem to tackle. The American physicist R.A. Millikan did it with the help of his famous oil drop apparatus. It is of interest to mention here that he experimentally found different values of 'e' for different drops. Even the reduction in air pressure inside the apparatus increased the apparent value of 'e'. He did not trust his experimental data and instead had a good look at the relevance of assumptions underlying Stoke's Law. This exercise resulted in the very modification of Stoke's Law which he had used in his earlier calculations. His experiment did not answer the basic question of granular structure of electron as well as the possibility of charge less than 'e'. At about the same time, F. Ehrenhaft obtained differing values for the charge on the particle. He even doubted Millikan's results. He thus hypothesized the existence of sub-electrons. However, Millikan received support in his result from Regener (1910), Ishida (1923) and Mattauch (1925) In 1930, A. H. Compton showed that it is quite possible to have a highly precise value of 'e' with the help of X-rays. In 1930-31, J.A. Beardon, using ruled gratings and crystals, obtained a value of 'e' which he found to be on high side. He did not believe in this value after experimentation. In the meantime, values of 'e' obtained from other methods, were found very close to the one obtained by Bearden. This led Shiba of Tokyo in 1932 to suggest that the trouble or the ground of conflict lay in value of viscosity used by Millikan in his calculations. In 1937, Bearden measured the viscosity of air to test the suggestion of Shiba. He found his new value on the high side by about. $.007 \times 10^{-4}$ CGS units. In 1937, Houston made a still more precise measurement of the viscosity of air and detected a small error made in it about twenty one years ago. A year later, Majumdar and Vajifdar in India also obtained similar values for 'e' and thus confirmed Bearden's results (e $4.806 \pm .003 \times 10^{-10}$). Lastly Dummond and Cohen on the basis of their work obtained $e = 4.80286 \pm .00009 \times 10^{-10}$ e.s.u. Why this exercise ? Because scientists think and work hard to measure the values of fundamental constants as precisely as possible which enter vitally into calculations in theoretical physics. Examples of such constants are the velocity of light, mass of proton and electron, magnetic dipole moment of the neutron, charge on the electron and the mass of atoms like hydrogen and oxygen.

This is not the end of the story. Rutherford posed questions about the structure of the nucleus as well as the motions of electrons around it which are somehow linked with the 'optical, electrical, magnetic, chemical and technical properties of atoms'. Answers to these questions began to be found out. It is now possible to calculate physical and chemical properties of matter with the help of the atomic physical theory thus making the science of experimental chemistry superfluous (Rice and Teller). In 1937, G.P. Thomson and Davisson shared a nobel prize for demonstrating diffraction effects of electrons. In their hands, electrons were accelerated to investigate crystal structure. Electron is no longer considered a particle having only mass and charge. Pauli, Goudsmit and Uhlenbeck attributed to it the properties of momentum : angular and magnetic. Electron was after all not a simple particle but it was a complex stranger to comprehend. From 1928 onwards, P.A.M. Dirac gave a brilliant description regarding the behaviour of electrons. But it suffered from a dangerous flaw. It rang the death knell of matter that is destroying everybody in the process. Attempts were, therefore, made to save the theory of Dirac by suggesting grudgingly the possibility of positions as 'Holes in an unobservable hypothetical sea of negative electrons'. To quote Dirac :

> It was not immediately obvious to me, however, as to just what the detailed mechanism was. Did the positrons somehow acquire the positive charge from the nucleus ? The idea that they were created out of the radiation itself did not occur to me at that time, and it was not until several months later when Blackett and Occhialini suggested the pair creation hypothesis in their paper published in the spring of 1933, in which they reported their beautiful experiments on cosmic rays using the first cloud chamber controlled by Geiger counters.[16]

Anderson discovered them by chance experimentally when he was investigating something else : the 'energy spectrum of the secondary electrons produced in the atmosphere and other materials by the incoming cosmic radiations'. Let us stop the story hereafter having first predicted and then verified positron, that is, the electron's cousin. What does the nature of pursuit in the Emergence of Electron as we know it today tell ? There is a vast difference in science as we find it in a textbook ; and the science which is in the making. The former looks so simple, impressive and logical ; and the latter so crude and faulty like horse behind the cart. Occasions are not barred when highly disturbing type of predictions are made first and then evidence sought or obtained later on. The situation other way round is also true—where past notions as well as experiences lose their relevance in the face of new observations or experimental facts. Free and uninhibited speculation is barred to none especially in our times, when problems are posed and solved from as many varied angles as feasible. In a given unknown situation, a wild guess is more respectable than no guess at all for the former does give some basis to rest upon on the basis of Window Tapping ; an activity not considered undesirable at all in Science IN the Making for the Makers of the Possible. It is like shaking The Black Magic Box to find its inside contents. The situation becomes more interesting and fascinating if inside contents come out of the box like liquid Helium making the distinction between the two (whether inside or outside) quite difficult. These chippings and scaffoldings constitute the marvellous intellectual admirations of Science IN The Making. It is in this context that the Hypotheses Setting ; and Varied Testing Approaches become the distinguishing characteristics of the Nature of Scientific Enterprise in our Times. We have to learn to live with varying degrees of vagueness in our thinking and doing. To quote Lewis and Randall :

> There are ancient cathedrals which, apart from their consecrated purpose, inspire solemnity and awe. Even the curious visitor speaks of serious things, with hushed voice, and as each whisper reverberates through the vaulted nave, the returning echo seems to bear a message of mystery. The labour of generations of architects and artisans has been forgotten, the scaffolding erected for their toil has long since been removed, their mistakes have been erased, or have become hidden by the dust of centuries. Seeing only perfection of the completed whole, we are impressed as by some superhuman agency. But sometimes we enter such an edifice that is still partly under construction ; then the sound of hammers, the reek of tobacco, the trivial jests

bandied from workman to workman, enable us to realize that these great structures are but the result of giving ordinary human effort a direction and a purpose.[16]

12. The Work of Humphry Davy

(Dec. 17, 1778—May 28, 1829)

During his childhood, he was not very serious about his school studies. Instead, he spent most of his time in observing, collecting, fishing, listening to stories, predicting and speculating in his own child-like manner. He drew one of the most ambitious plans for his futuristic Self Education which included religion, geography, my profession (botany, pharmacy, nosology, anatomy, chemistry and surgery), logic, seven languages (English, French, Latin, Greek, Italian, Spanish and Hebrew), physics, mechanics, rhetoric, history, chronology and mathematics. At Dr. Tonkin's place, he carried out chemical experiments, with danger to self and others, assisted by his sister who quite frequently complained of 'ravages committed on her dress by corrosive substances'. In 1798, he dared to attack Prof. Lathom Mitchell's Theory of Cantagion by showing that nitrous gas did not spread disease when inhaled by animals or when exposed to wounds. He thus came into the notice of Dr. Thomas Beddoes who was about to establish a Pneumatic Institution in Bristol with the object of combining chemistry and medicine. Thus he became the first superintendent of the newly established institute. This institute, aimed to ameliorate human suffering, wholeheartedly, welcomed those patients who had been declared incurable or hopeless by their medical doctors. The research treatment consisted in inhaling varying proportions of the then known gases like oxygen, hydrogen, nitrogen, carbon monoxide and nitrous oxide. Interestingly enough, many patients got cured sometimes even without inhaling any gas but air. It was a short lived reputation for the institute because under controlled conditions, the results were not very encouraging. In his earlier work and speculation, he received more of admiration and less of critical examination at the hands of Dr. Beddoes who edited and published his work in 'Contributions to Physical and Medical Knowledge Principally Drawn From the West of

England'. This hasty publication was badly criticized by the prominent British scientists for they showed that conclusions had not really followed from the main experiments themselves. In July 1880, he wrote a six hundred pages treatise on 'Researches: Chemical and Philosophical concerning Nitrous Oxide and Its Respiration' which brought him immediate name and fame. It consolidated at one place the preparation and properties of the then known compounds of nitrogen as well as effectiveness of nitrous oxide for medical treatment. It is of interest to point out here that he still regarded air not a mixture of gases but a compound. He also entertained the idea that hydrogen and nitrogen were compounds rather than elements. His heart did not appear in medical field but in pure chemical research; he did not at all follow up the potentiality of using nitrous oxide gas for controlling physical pain despite the fact he had used it on himself when he had suffered badly from the ache of his wisdom tooth. In his enthusiasm, he did not hesitate, despite contrary evidence, to experiment with all the known gases on himself including hydrocarbonate which had earlier killed Dr. Beddoes experimental animals. To quote Davy :

> Having already inhaled for nearly a minute three quarts of hydrocarbonate mingled with nearly two quarts of atmospheric air, it produced a slight giddiness and pain in the head, and a momentary loss of voluntary power; my pulse was rendered much quicker and feebler. These effects, however, went off in five minutes, and I had no return of giddiness.
>
> Emboldened by this trial......I resolved to breathe pure hydrocarbonate. For this purpose, I introduced into a silk bag four quarts of gas nearly pure, which was carefully produced from the decomposition of water by charcoal an hour before, and had a strong disagreeable smell.
>
> My friend, Mr. James Tobin, Jr., being present, after a forced exhausting of my lungs, the nose being accurately closed, I made three inspirations and expirations of the hydrocarbonate. The first inspiration produced a sort of numbness and loss of feeling in the chest, and about the pectrol muscles. After the second inspiration, I lost all power of perceiving external things, and had no distinct sensation, except a terrible oppression on the chest. During

> the third expiration, this feeling disappeared, I seemed sinking into annihilation, and had just power enough to drop the mouth-piece from my unclosed lips.
>
> A short interval must have passed, during which I respired common air, before the objects around me were distinguishable. On recollecting myself, I faintly articulated, 'I do not think I shall die". Putting my finger on the wrist, I found my pulse threadlike, and beating with excessive quickness. In less than a minute, I was able to walk, and the painful oppression on the chest directed me to the open air.

On April 30, 1800, he learnt that William Nicholson had successfully decomposed water into hydrogen and oxygen by using a Voltaic pile. He was elated because this discovery would give him inexhaustible supply of hydrogen and Oxygen. Strangely enough, he was quite ignorant of the Voltaic pile itself. Soon enough, he learnt about it and discovered facts about electrolysis. For example, he failed to decompose chemically purified water. Within a short time, he published six papers on electrolysis. Right at the commencement of this experimentation, his brain wave suspected an 'interchangeability between chemical and electrical energy'. On inadequate evidence, he asserted boldly that chemical effect and electrical effect were interconnected. This work brought him under the eye of the Royal society in London which he joined at the age of 22 years. There Count Rumford found him quite repulsive at the first instance and refused to let him speak in the main theatre until he had shown his effectiveness in the small lecture rooms. His first lecture there was a great success which earned him promotion (he became a lecturer), reputation and publicity. He was asked to deliver another lecture, later on, on the Chemical Principles of 'The Art of Tanning'. In his lectures, he stimulated inquiry rather than provided factual information. He stated that science could conquer human suffering to a considerable extent : 'we look for a time that we may reasonably expect for a bright day of which we already behold the dawn'. He continued his studies in electrochemistry. In 1802, he became a fellow of the Royal Society. He also won a medal from the French Academy for the best experiment on Galvinic Fluid at a time when England and France were at war. He also fiercely attacked John Dalton, though he accepted his Law of Definite Proportion yet considered his 'speculations from this law as spurious'.

It won't be out of place to talk in passing about the safety lamp. The Watt's Steam Engine enabled miners to dig deep and deeper mines. This led to explosions which killed several miners every year. It was a great human misery, of course, avoidable, if something could be done to the highly combustible gas : Fire Damp. John Buddle, an expert in coal mining, had already suggested for the scientific solution of this problem by scientific minds. In this regard, the Royal Society had received several varying solutions to control these explosions. It is of interest to note here that Dr. Trotter had suggested the use of chlorine gas to extinguish fire damp, a remedy, if applied, would have killed the miners themselves. Naturally, the choice fell on the Man of Science, Davy. He studied the problem and did the job by designing an efficient lamp. He received admiration and gratitude from the miners as well as their authorities. As usually happens in the history of science happened here as well. George Stephenson staked his claim for this discovery. Many people began to believe that basic invention had been done by Stephenson. Davy here mildly reacted by providing data that Stephenson's safe lamp was not in fact safe at all. Davy then was requested by many of colleagues and advisers to get this lamp patented for this would then provide him with not less than 25,000 dollars per year. Davy replied back in the following words which Madame Curie were to echo later in the next century :

> I never thought of such a thing : my sole object was to serve the cause of humanity ; and if I have succeeded, I am amply rewarded in the gratifying reflection of having done so......More wealth could not increase either my fame or my happiness. It might undoubtedly enable me to put four horses to my carriage ; but what could it avail me to have it said that Sir Humphry drives his carriage and four !

What is the greatest discovery of a scientist ? One receives several answers. It is said of Torben Olof Bergman, a well-known Swedish Chemist and Physicist, that his greatest discovery was Karl Wilhelm Scheele. Davy, similarly, discovered a book binder named Michael Faraday who turned out to be more than a mere bottle washer ; and ultimately chaired the Royal Society. On March 5, 1823, Dr. Paris chided Faraday for using dirty test tubes in his experiments with chlorine and chloral hydrate in closed tubes. Faraday agreed with his judgement, felt sorry and filed off the sealed ends. A jolly good explosion took place ! The dirty oily matter immediately disappeared. It was a big discovery : liquid of chlorine under unexpected circumstances. On learning this, Davy came to see Michael Faraday's experiment. Now Davy and Faraday tried the same technique on several gases successfully. To Faraday's great surprise, Davy presented the final report in a manner as if Faraday had been simply a helper in this whole episode. For reasons, best known to himself, Davy also actively opposed the membership of Faraday to the Royal Society. Personal relations between them which were already strained still worsened further. Let us come back now to the safety lamp. The deaths in mine, as already postulated, did not go down. There were several reasons. Deeper and deeper mines were dug with the assistance of safety lamp. The miners found security in the safety lamp and hence became careless. Possibly, the flame escaped when the gauze of the lamp became extremely red hot to cause explosion. Naturally, the British Government set up an inquiry committee comprising members of the Parliament to report on safety lamp. Perhaps the question posed was a bit loaded ; 'was it possible that the device would be dangerous under certain conditions ?' Although loyal to Davy, he had to tell the truth which made Davy quite furious. Both hammered their laboratory with fascinating question passionately, persistently, truthfully, reflectively and successfully as well.[17]

13. George Westinghouse

(Oct. 6, 1846—March 12, 1914)

Let us now refer to a person who was neither a mathematician, a scientist, nor a technologist. He was an inventor who inherited not only mechanical aptitudes and manual dexterity but also christian name of his father for he too closely resembled him physically. Out of affection, grandson was also named George. Let us talk of the middle George who suffered from serious tantrums during childhood. If he needed a thing, he demanded it—And he got it. If he did not get it, he would strike his head either against floor or wall until it bled profusely. At school, he got into serious trouble with the seniors for he beat them and was in turn physically beaten. This resulted in his lonely wanderings which developed his interest in plant life, animal life, and, in short, having close looks at the beauties of nature. The school teachers complained of his poor progress. He was intelligent but did not apply his mind to the various school subjects. His failure at school seriously worried his parents. His father's shop fascinated him for the multisensory approach to self-learning for him lay there 'where he could tune his ears to the din of heavy machinery; and drink in the smell of fresh grease and hot iron'. As the opportunity was provided, he began to cut classes at school and stay as much as possible at the shop studying many things first hand. This infuriated his father who planned to dampen his enthusiasm by offering him reluctantly a paid apprenticeship during vacations. He was given ordinary chores like cleaning floor and tables and scrubbing machinery etc. which were little related with his inventive powers. He protested in vain about this maltreatment but again, against such heavy odds, his will to stay there did not weaken. His father could free him in the afternoons in case he was interested in swimming. The son again mastered the temptation and therefore refused the offer reluctantly. He had to pass another test. One hot afternoon, when all the employees had left the shop, his father asked him to cut manually about a dozen iron pipes, single handed, as part of the order just received by him a couple of minutes ago. He again protested by saying : Why this Discrimination ? He had to yield and do the job. Like the stupid chimpanzee, he surveyed the whole situation. He saw the steam engine still hot and fuming and thought of fixing the saw to one of the lathes, a feat which had not been tried before. He did his job in a few hours and returned home whistling. It was a job very well done. His father rebuked him badly for being careless at the shop because it was a tough job which required a few days, at least, to be accomplished. He was surprised when the son said that he had done the job. He took his father to the shop for confirmation who in turn felt proud of his son ; He exclaimed :

> George, though you are my own flesh and blood, I do not think I will ever quite know what to make of you ?

This achievement fired his imagination in the use of steam engine and steam power. To his utter dissatisfaction, he found current steam engines wasteful and inefficient in many ways. He now lived in a world in which pressure, temperature and control valves were more important than anything else. On his return from military service, he helped a rail carriage put on the crack. In his view, it was one of the clumbsiest jobs ever done. Why do not they think of doing something else ? Then he told his father clearly that he wanted to become an inventor. His father retorted back by saying that most of the time inventors starve in their lives. He further disclosed that he wanted to invent a car replacer about which his father knew the least. His father talked of supporting his college education which offer his son accepted half heartedly. He readily found that the college was not made for him. In the meantime, his application for patent on rotary engine was accepted. He was full of wild enthusiasm for earlier he had failed as a son, school boy, army recruit and so on, Enthusiastically; he began to work on his car replacer which was a success as the design turned out to be quite simple. His contacts with railway officials increased ; and he learned from Towne, particularly speaking, about other problems facing them in general. One of them, specifically speaking, was the inefficient application of brakes. Hand braking, then applied, was so crude and efficient. George gave a thought to this problem and after some time discussed the tentative proposal (chain type) with Towne which turned out to be the same as submitted by Milwaukee man earlier. This frustrated George and he tried his best to hide his feelings. He did not lose heart. He now tried steam but unsuccessfully because it was difficult to eliminate temperature and even condensation. Then in his utter frustration and exasperation. he received inspiration from an article in the Living Age which suggested him to use Air 'which when free exercises an expansion force equal to six atmospheres'. If true, this will eliminate dual problems of condensation, and using steam engines as well. All laughed when he talked of his invention to friends and officials. It was more absurd than the first suggested use of parachute in war. The result was that nobody offered him facilities for a try out. Even Towne did not help. He had now changed his venue of work for business reasons. There a friend named Braggley was fascinated by this air breakes idea. He offered to invest his savings into this promising device as he put it. Again there was no immediate offer of a try out. But it did come. The superintendent Card was too much impressed by this efficient device which in fact he did not hope to see in his life time : a glass of water placed on the floor of the last carriage stayed undisturbed on the application of air brakes. Further, the brakes behaved very efficiently at high speeds, low speeds and steep gradients. Still, the trains ran late because their traffic signalling was chaotic. He also tackled this problem, in which he was least interested successfully.

George was fundamentally an adventurous man. He intuitively touched problems, solved them with or without assistance, whatever may be the cost of experimentation. Some how he got interested in the commercial exploitation of gas. He read a bit about geology while he was on a short visit to New York. At a cost of 5000 dollars to self, he requested one of the experts to dig a test hole in his compound. He thought at one time that whole of the adventure was lost. One early morning, the gas well exploded. How to cap the gas well became a serious problem? He tried a heavy wooden plank which broke into pieces, and a hundred pound stone flew like a balloon. He made arrangement for testing the properties of this gas. Then the idea of Stop Cock and Escape struck him which made feasible to pipe the gas to the town in the face of serious opposition. In this field alone, he had thirty-eight patents to his credit. Then he turned his talent to electricity. Alva Edison's lamp did not make as much headway as expected because it was becoming difficult to power these lamps with D.C. He read about transformer in a pamphlet as developed by Gaulard and Gibbs. He purchased this patent at a cost of 50,000 dollars ; and shortly afterwards changed it beyond recognition by replacing discs with wires. In this, he had been assisted by one of the young engineers named Stanley. On grounds of health, he expressed his desire to leave for his home place George respected as well as supported talent generously. At full expense, a laboratory for him was set up at his home place where he was again to be assisted by a junior engineer named Belfield. George went to the extent of importing a dynamo from England for Stanley despite there being no budgetary provision for the same. It was no wonder then that Stanley, supported intellectually, emotionally and financially by George with the sense of history, succeeded to set up a full scale generating plant which fed 400 incandescent lamps four miles away. George, like Davy announced that the age of electricity had dawned for the benefit of mankind. George did not stop at this. He now wanted a jolly good alternating current motor to be designed by an inventor who could announce its price as well. Here again he came across a highly educated and gifted engineer named Nikola Tesla who had worked on Polyphase Alternating Current system which eliminated commutator, brushes and other unnecessary connections to make armature spin freely. Like George in his early years, he was a person who had no money to finance his most potential patent. He had worked with Edison, and told George that Edison could not, despite his many efforts, grasp the full significance of this motor. Secondly, Edison registered Tesla's patent in his company's name, and the latter received nothing. George knew about these malpractices and bought his forty patents at the cost of one mlllion dollars plus handsome royalty. Nikola Tesla did not believe this offer and considered it a heavenly gift. High voltage at the hands of George also resulted in the development of electric chair for electrocution purposes. A paper warfare stated with Edison which George least wanted. Temporarily, Edison had an upper hand because of his connections, and the link of death by electric chair to A.C. in public mind. George hit back by saying that there are many things like gun powder, whisky and over eating which kill people. A.C. can kill but it does not mean that it cannot be controlled efficiently unless a 'man is fool enough to swallow the whole dynamo'. The work on the motor began. Here the chief difficulty lay not in the motor which worked on a 60 cycle frequency but in adjusting the motor to the 133 cycle frequency standard established by

George for A.C. This exercise ended in failure despite lot of money poured into making the motor a success. His financial troubles increased and in his darkest moments, he did not lose faith in Makers To Happen whatever may be the cost. He told his bankers who refused to back him up in the following words :

> Without research, there would be no transformer, no alternating current equipment—indeed, there would be no Westinghouse Electric Company. Progress is our most important commodity. We invent and develop new and better things for the long range benefit of the nation and its people, I am an inventor. Financial profit alone does not intrigue me. If ever the time comes when that is the only concern of the Westinghouse Electric Company, I will no longer be associated with it. Is that clear, gentlemen ?

> I understand it (business interests) perfectly well. Since I am not a banker, I would never presume to tell you how to run your bank. Similarly, I will not permit anyone to run my company.

Despite heavy financial commitment, he agreed to the viewpoint of Tesla who was more of a scientist than an inventor. With little profit, he illuminated the World Fair (The Columbian Exposition) at Chicago in 1893 with 2,50,000 lamps at less than half the cost quoted by Edison's company. He infact designed his own two piece lamp as he expected some trouble from Edison's side. He designed an air pump for evacuation purposes. He used more or less the same set up to harness the kinetic energy of the *Niagra* Falls to produce electricity. He firmly believed in inventions to invent inventions. He then improved upon steam turbines. Before his death; he designed air springs to make horseless travel smooth and comfortable. He had 300 patents to his credit which ranged from Car replacers through complicated electric controls to an improved design for turbine blade.[18]

14. Measuring the velocity of light

It is a fascinating story which tells us how the velocity of light was actually measured. Our ancients took lot of interest in the phenomena of light including formation of optical illusions.

Even about twenty three hundred years ago, the Greek philosophers had investigated light. They knew, for example, that light travels in a straight line, and angle of incidence equals the angle of reflection when ray of light falls on a plane mirror. They were also not unaware about the phenomenon of refraction. Claudius Ptolemy measured empirically the angles of incidence and refraction but could not state the wellknown Snell's law. With the possible exception of Empedocles, the greek philosophers believed that the speed of light was infinite. Aristole, authority on natural knowledge, also believed that the speed of light was infinite. This belief held sway for several hundred years for neither any method nor any instrument existed to measure this, short of impossible, speed. Over nine hundred years ago, two Islamic scientists Avicenna and Alhazen speculated over the speed of light. Presenting experimental data, they suggested that the speed of light was definitely finite. This figure would be, of course, quite large in their opinion. The Italian genius Galileo attempted to measure the speed of light by using artillery fire at great distances as well as lanterns on hill tops. He also found the figure too large. Doubts still existed regarding the infiniteness of the speed of light. Robert Boyle considered it finite whereas Johannes Kepler, Rene Descartes and Robert Hooke considered it infinite. In an effort to develop better maps, a search was made for a celestial event which could be used as a set standard for recording time both at sea and land in Paris. It turned out to be the eclipse of one of Jupiter's four large moons. Ole Roemer, on the basis of mathematical culculations, obtained the figure of 1,38,000 miles per second in 1676. He thus brought an infinite speed within the 'compass of reason and human measurement'. The Paris philosophers distrusted this figure as well as the basis of his method. James Bradley confirmed Roemer's figure by using an entirely different method in 1729. The critics insisted on a terrestrial method like the usual method of determining the speed of sound. In 1849, A. H. Fizeau using mirrors and toothed wheel obtained a figure of 1,94,000 miles per second. The controversy then arose regarding the reliability of this figure. Jean Foucault in 1855 obtained a figure of 1,85,000 miles per second on the basis of a method involving a rotating mirror as suggested by Arago in 1842. He also measured the speed of light in another medium, namely, water. In 1872, Marie Alfred used modified wheel with two hundred teeth in it and obtained a figure of 1,86,000 miles per second. It was in this year that Albert Abraham Michelson was answering the question in examination on Focault's method of determining the speed of light at the United States Naval Academy at Annopolis. He had joined Navy because his parent could not afford higher education somewhere else. Even here, he did not get the place at first try. He himself went to see President Grant and requested earnestly for a place saying, "I will make you proud of me if I get an appointment". In his scientific eminence, he regarded it as an illegal act.

Michelson was not satisfied with the earlier experimentally obtained values of c. He made several modifications in the Focault's experimental set up. He lacked financial resources to purchase expensive equipment. He, therefore, gathered odds and ends, tried his best to improvise apparatus from some of his academy demonstrations. Using plane mirror, rotating mirror, convex lens and toothed wheel, he reported in May 1878 the figure of 1,86,508 miles per second, for the velocity of light. The Naval Secretary granted a research assistance of five thousand dollars to Newcomb for trying new experiments on the velocity of light. Michelson stayed there for a little while with Newcomb. He got his father-in-law interested in his research who gave him about 2000 dollars. He repeated his experiment twenty times and obtained the value of 2999,853 Kms. per second, that is, just over 1,86,000 miles per second. This figure remained an acceptable figure for about forty five years. It was again Michelson who improved upon this figure later on. He considered it a great fun to measure the speed of light. He left for Europe in 1880 and met several great scientists there.

Let us divert for a while here. His European visit kept his mind in ferment. He reflected seriously on the nature of light predicted to be electromagnetic in character by Maxwell. Light needed a medium for propagation which by its nature of properties attributed to it was neither solid, liquid nor gas but did possess part of their properties. It was the 'luminiferous ether' considered to be a fifth element even by Aristole. In scientific terms, Christian Huygens in 1678 was the first person to propound this idea in order to explain the behaviour of light. He needed this medium to carry his hypothetical waves. Newton also suggested wave and corpuscle concepts to explain certain unusual behaviours of light. He also believed in Ether hypothesis. To quote Newton :

> To suppose that one body may act upon another at a distance through a vacuum, without the mediation of anything else, is to me so great an absurdity that I believe no man, who has in philosophical matters a complete faculty for thinking, can ever fall into.

This scientific difficulty attracted the imagination of Michelson. He passed sleepless days and nights to ponder over this 'gossamer of Physics' having no body, shape or form. In the Phraseology of Sir Oliver Lodge, the experience of ether was analogous to the experience of a deep sea fish which does not apprehend 'the existence of water for it is too uniformly distributed in it'. Maxwell himself had doubted whether answer to this problem could ever be found. He had, however, said :

> If it were possible to determine the velocity of light by observing the time it takes to travel between one station and another on the earth's surface, we might by comparing the observed velocity in opposite directions determine the velocity of the ether with respect to these terrestrial stations.

Michelson grappled with this problem. He developed his own instrument called interferometer partly based upon Fizeau's technique, which he had used in 1851, in another experiment. He did not find any shift in interference fringe system. The negative finding failed to detect any ether wind and showed that the hypothesis of stationary ether was erroneous because Earth could no longer be regarded as stationary. The evidence indicated that there were still two possibilities, namely, earth dargging ether in its journey round the sun and the very non-existence of the ether itself. This finding raised a controversy in which Sir Oliver Lodge and Lord Kelvin continued to believe in the existence of ether. Michelson did not keep himself away from this controversy. In April, 1887, Michelson and Morley collaborated on another experiment in which they again got a negative finding, after making thousands of observations daily in sixteen different directions' while the earth was constantly changing its distance'. At the start of the experiment, Morley in April 1787 had written to his father. Michelson and I have begun a new experiment 'to see if light travels with the same velocity in all directions.' 'I have no doubt that we shall get decisive results.' John D. Bernal has called the finding of this collaborative experiment as the 'greatest of all negative results' in the history of science. It denied the existence of stationary ether or the negative finding indicated that the earth dragged the ether all along its way at its own speed. There was again a negative finding when this hypothesis was tested ten years later. By another ingenious experiment, Sir Oliver Lodge showed that ether was at rest. It is no wonder then that nature of light, existence of ether and the meaning of absolute motion became a matter of personal opinion. Interestingly enough, the negative finding of Michelson and Morley could be explained both with and without the existence of ether. At this point, George F. Fitzgerald and Hendrik A Lorentz on the basis of their mathematical reasoning suggested a Contraction Hypothesis which meant that a moving rod shrinks when its velocity increases. It does not vanish because at the same time it begins to become heavy as well. According to their calculations, the arm of the Michelson interferometer would contract one part in 2,00,000,000, a contraction of which Michelson and Morley were not aware. This contraction hypothesis rested on the classical laws of Newton.

Other independent paths also began to converge : the work of J. J. Thomson, Marie and Pierre Curie, W. Kaufmann and Max Planck etc. It was now left to Einstein to solve the Chinese puzzle of ether drift, velocity of light, relevance of absolute motion, variability of mass, nature of energy and the relationship between mass and energy. Einstein had a furious 'impulse to understand, to be informed and to think for himself'. He saw relevance in past ideas but did not hesitate to question them at their weakest points. He regarded common sense as 'a deposit of prejudice, laid down in mind prior to the age of eighteen'. In his equation, there was no need of ether. He, therefore, regarded Michelson Morley finding as perfectly correct. In 1924, Michelson was asked to repeat his past experiment which he did reluctantly by saying that 'we shall prove only that the earth rotates on its axis, a conclusion which I think we may be said to be sure of already'. Again the negative findings were confirmed. By an ingenious alteration, Roy J. Kennedy in 1828 confirmed the negative findings of Michelson Morley experiment. Michelson then commented as follows : 'Your work renders my own quite superfluous, I should not have undertaken it had I known you were doing it so well'. The nature of controversy created its own weapons to kill itself. Michelson received experimental support from Auguste Piccard who sent a small interferometer in a balloon one mile and a half above the ground as well as from Louis Essen who had used a cavity resonator about ten times more accurate than Michelson's interferometer. In 1960, his work received experimental support from, MASER as developed by C. H. Townes whose 'accuracy was one part in a thousand billion, the most precise physical experiment in history'. In 1907, Michelson received a noble prize for exactness of measurements and investigations in spectroscopy.

It is very rarely that a great man of science in his old age returns to the same problem which he had tackled in his youth. At the age of seventy, he returned to his beloved problem, namely, measuring the velocity of light exactly. Between 1924 and 1927, he took five independent sets of measurements and obtained a figure of 186,175 miles per second. He was not satisfied because the conditions for precise determinations were not available. Before the final try, he obtained a research grant of sixty seven thousand dollars but, unfortunately, at the same time also suffered from cerebral haemorrhage as well. He prayed to Light to give him a few hours of life only for this precise determination because it was to be made in nearly vacuum conditions. Physical hurdles in the execution of his experiment were immense. Evacuation of a long tube and maintaining a very low pressure were the chief ones. Less than 3000 determinations were made and the average speed of light came out to be 14 miles less than the earlier figure. This figure is less by 18.5 Kms. than the present accepted value. There is generally no last word in scientific adventure. The scientific cathedral always tends to remain incomplete. Once firmly established ideas are continually challenged, examined (theoretically as well as practically), improved, refined and even replaced by superior ideas. More precise determinations were made in U.S.A., Germany and England. Slight differences in its speed before and after the Second World War led to another interesting hypothesis that the velocity of light is itself variable. To put in other words, it has changed over the years. It is just possible that new measurements, new techniques and new methods may lead to a new discovery. Let us end this fascinating account by a public attribute of Einstein made in appreciation of Michelson's contribution :

> I have come among men who for many years have been true comrades with me in my labours.... You, my honoured Dr. Michelson, began with this work when I was only a little youngster, hardly three feet high. It was you who led the physicists into new paths, and through your marvellous experimental work paved the way for the development of the Theory of Relativity. You covered an insidious defect in the ether theory of light, as it then existed, and stimulated the ideas of H.A. Lorentz and Fitz Gerald, out of which the special theory developed. Without your work, this theory would today be scarcely more than interesting speculation ; it was your verifications which first set the theory on a real basis[19].

15. The use of history of science cases

We have already discussed at depth the Nature of Scientific Enterprise. The present day science text-book as well as the science teacher does little of credit in familiarizing our young boys and girls specializing in sciences and arts with the real structure of science. The consequence is colossal ignorance in regard to the spirit, methods, procedures and personal characteristics of scientists. Not science but syllabus is taught, learned and examined mechanically. This conern led Conant and others in the sixties to introduce the use of Case Histories or Studies at the college level for those who were majoring either in social sciences or humanities at Harvard. Some examples are : Robert Boyle's experiments in Pneumatics ; The Overthrow of Phlogiston Theory ; The Chemical Revolution of 1775-1789 ; The Early Development of The Concepts of Temperature and Heat ; The Rise and Decline of the Caloric Theory ; The Atomic Molecular Theory ; Plants and The Atmosphere ; Pasteur's Study of Fermentation ; Pasteur's and Tyndall's Study of Spontaneous Generation ; and The

Development of The Concept of Electric Charge : Electricity From The Greek to Coloumb. Incidentally, they, popularly called, Case Histories in Experimental Science, also reveal the reflective basis of science even to scientists and science teachers who in the name of modernity show little interest in the history of science. To quote J.B. Conant :

> The purpose of the case histories presented in this series is to assist the student in recapturing the experience of those who once participated in exciting events in scientific history. The study of a case may be to some degree the equivalent of the magical operation, namely, that of transporting an uniformed layman to the scene of a revolutionary advance in science. To be sure, usually more than one investigator or laboratory is involved and the period of time is at least several years ; for however, significant a single experiment may seem in retrospect, no important step forward in ex- perimental science rests solely on the record of any single investigator's observations. Rather, the interplay of ideas of several men, arguments about experiments and their in- terpretation between workers in different laboratories often mark the decisive turn in scientific thinking. However, by the intensive study of the actual work of some of the great investigators of the past (and in less detail the work of their contemporaries) the methods then employed stand clearly.

It is only in few classrooms that a teacher relates a few anecdotes and, at best, if he is well informed, tries hard to link current topic of the day with the past researches which made that topic possible. For example, while teaching electromagnetic induction, he will link Faraday's work with the works of Volta, Oersted, Arogo, Ampere ; and Humphry Davy who filled in the gap between Volta and Faraday. Leo. E. Klopfer, influenced by Harvard Histories, went a step backward in 1960 by developing experimental texts on some of the major past episodes of science for the benefit of high school students : The Discovery of Halogen Elements : The Chemistry of Fixed Air; Frogs and Batteries ; Air Pressure ; Fraunhofer Lines ; and a few others. Their basic aim is not primarily to teach scientific content but to give student the feel of science, the way the scientists worked in the past, to share with them part of their ecstacy and frustration. More specifically, the basic aims of these case histories are to know and feel at depth about the methods, procedures and techniques used and developed by scientists in their work ; factors and facilities which favour or hinder scientific advance ; the personal characteristics and habits of scientists ; value and role of accurate and accessible records, sensitivity of equipment and apparatus ; and free communication ; and interrelationship of social, economic, political technological and psychological aspects of a given period with the progress of science. It will be thus apparent that it is not easy to develop a good case history of science illustrating the birth and its impact at a particular period in the history of a major scientific idea or discovery which moved the world. Secondly, it makes available sufficient scientific experiences of those times (not moving fast as today) for achieving those objectives of science teaching which are difficult to achieve through other methods employed to teach content. For example, opportunities for problem-solving through simple and cheap equipment (used by the world famous scientists), opportunities for practising scientific methods and the various aspect of scientific attitudes and the development of scientific appreciations etc., are available in abundance when case study method is used. Incidentally, it then also links science with economics, history, sociology, politics technology and even psychology.[20]

Concluding statement

Science, at its best, is taught factually in our country. Here also, the entire teaching including practicals is dominated by the 'Goddess of Examination.' The young teachers, with vibrating minds, find it very difficult to beat the system. Majority of old teachers, on the other hand, follow highly routinized habits of teaching ; and consider any change in these unnecessary and fruitless. Those who among them become administrators are more interested in the maintenance of *status quo* than in inviting intentionally new ferments, during their tenure. Consequently, excellence is not built into the hierarchy, and research and innovation are not built into the system. There is another reason as well. Research in science Education is not a rewarding career. This also hits science badly for reforms in science education are made on opinions and whims rather than tested evidence. These are some of the reasons which continue to keep our science education at the subsistence level. To have a close and critical examination of what we do by itself constitutes an educative experience. What was then the purpose of this chapter ? It was to reflect as fully as possible the structure of science, static and dynamic or stable and fluid. Secondly; advances in science stem from man's efforts to make sense of what he sees and experiments. In this context, science concepts are man-made and hence tentative—which classify, and interpret his observations. It is these concepts which through the mechanism of self-correction attempt to build a complete model of the universe, an impossible task worth challenging eternally. One should not lose heart in the face of preliminary failures for it is at this moment that the real picture of science would ever appear. Like Archimedes twenty three hundred years ago, J.E. Teeple, a chemist, in this century entered the bathroom twice with a problem in his head. Unconsciously, he carried out all the usual bathroom chores Discovery : the towel was wet. It should not be lost sight of that 'Eureka' moments are few and far between in science. Einstein once said of him that he had to make ninety nine mistakes before he could arrive at the hundredth correct answer. Dr. Teeple's experience in this context is quite typical of problem-solving behaviour in science. Science is no longer a search for truth but a search for error. The test, according to Rudalph Flesch is simple : "If the thing is shot through with PERHAPSES and MAYBES and HEMMING and HAWING, it is probably science ; if it is supposed to be the final answer, it is not.[21]

5. *Exposure to Fundamental Scientific Phenomena*

Science, like children, goes through various stages. The first is that of collecting data. The second is that of dividing phenomena in groups which we may call physical or chemical until, eventually, we are led to a deeper understanding, to principles which collect the apparently isolated phenomena—and chemistry becomes atomic physics or physics becomes mathematics. There is no need to take our students through this long struggle. Having reached this understanding and generalization, we can start from there and work backward. I recognize that data are necessary and that one reaches principles through data, but data in themselves are boring and meaningless. They only serve to lead us to principle. If we start with principle, the data become alive and interesting principles which connect the data and the single phenomena. The unification of knowledge is the greatest achievement of science, perhaps the greatest achievement of human mind. We understand the sun since we understand the atom. We start teaching them the structure of matter and build from there.

Schools should teach nature and not physics and chemistry. How can we tackle such a subject ? Faraday gave one answer when he talked to children about a candle. He did not talk about the physics, or chemistry of the candle, but talked about the candle and slowly led the children into its chemistry and physics, fascinating his audience. I would take children out into nature and look around, then say, pick up a stone, and

> then let it fall. The weight of the stone and its fall would lead one into gravitation, the forces holding our solar system together. Then I would perform Galileo's famous experiment and drop a big stone and a small stone and see them reach the ground simultaneously. I would also throw a stone which would lead into mechanics, to force, momentum and inertia. I would follow up by putting a piece of lime stone into hydrochloric acid and see it dissolve, which would take me into chemistry and eventually to its centre, the table of Mendeleev. There is nothing one cannot explain to children, if one can preserve the child-like simplicity and naivete of one's own mind. With such a direct method, one could not only explain nature but make it absorbing, interesting, gradually working one's way upto biology and living things. One could give a really deep insight into nature's workshop.
>
> ...Produce men who know why and what they are, with eyes on the future, who are masters and not servants of creation. That is also the object of education.
>
> —Szent Gyorgyi

> The experience of doing a science project can provide a student with new knowledge and new skills as he works in the laboratory, workshop, field, or library. However, the greatest good that comes from project work is the personal experience of pursuing scientific discovery. In an investigative type science project, the student first becomes intrigued with a natural phenomena. He then finds out all he can about the phenomena by exploiting the available sources of information. When he reaches a 'frontier' of knowledge, he asks in experimental question—a question that must be answered by an active search.
>
> —K. C. Goyal and Piyuish Swami

Introduction

Science teaching in our country is neither theoretical nor practical. It is, for all practical purposes, bookish ; and precisely for this reason, it is found dull, dead and boring by a vast majority of our school boys and girls. This sorry and dissatisfying state of affairs can no longer be tolerated for with the assistance of five year plans, we are shaping our country into a modern scientific and technological based society. For this very reason alone, the scientific education of our boys and girls acquires special importance. What is the main problem here ? It is to expose our young boys and girls as fully as possible to the varied aspects of investigative science in different ways. For this we have to focus our efforts on the development of logical thinking in general and scientific thinking in particular among our science students at an early age by exposing them to fundamental scientific phenomena, structured experiences for the average and less able also included. Like Faraday's children, they encounter the problem as a whole rather than the physics, chemistry and biology aspects of it. They then see the problem in its multivaried aspects which enhances and heightens their curiosity. Then they put all sorts of questions first to the phenomena and secondly to themselves, the former help to see the problem or clarify it; and the latter, for choosing the most fruitful question for investigation. In fact, this whole exercise is intermingling of the two, and they thus plan their strategies relative to the investigative problems at hand. In their spare times, they work out these strategies which enliven their scientific knowledge—and fire their constructive imagination. A project thus gives a first hand experience and intimate knowledge of various research tools in science including library research and improvisation or fabrication of equipment.

Functions of Investigative Projects

Though investigative project, one can easily achieve the following purposes :

(a) It introduces and develops scientific facts, concepts and principles in an intimate manner among students through active and extensive encounters with the problematic situations which stem from natural phenomena within their immediate experience.

(b) It not only fires imagination but also motivates students to acquire the relevant scientific skills (abstract, communication, and concrete), deepened scientific interests, attitudes, and appreciations.

(c) It helps and encourages in the discovery (identification) and development of talent in the country.

(d) It may provide, if given the facility, first hand contacts with first class scientists for those who really complete an advanced investigative project.

(e) Lastly, it can be bent to supplement classroom teaching.

Posing the Problem at Depth

Not incidentally but intentionally, it is the job of science teachers to sensitize their pupils to several problems like a scatter gun approach, in their day to day classroom teaching. It is only then they will now that science remains an 'Unfinished Business'. In this connection, it is of great interest to reproduce below part of the talk of G. Guru on Investigative Projects in Zoology delivered to the practising science teachers under the auspices of the science Youth Project at the Regional College of Education, Ajmer.

Investigatory Projects in Zoology Purpose

Biology is a living science full of interesting and intriguing questions. The main objective of these investigatory projects in biology is to involve students in an active quest which makes them scientists in search of discovery in this discipline. The present projects have been selected and designed to serve the investigatory functions of school science students. The projects present problems to the students. Starting with an unknown, he will try to find out the answers and make the discoveries himself. Suggested approaches have been given so that in making discoveries for himself, the student will generally follow in the footsteps of scientists who have preceded him. But he is free to follow an entirely new approach and on some occasions he has to. The student should constantly keep in mind that there is the Possibility of Alternate Procedures. He should be always in search for new problems and design his own experiments to investigate them.

Selection of the Projects

Biology is a vast land of wonder and enigma, full of interesting and intriguing problems. Investigations in this most interesting branch of discipline may be conducted according to individual taste and choice, interest and quest in the following broad directions :

I. Investigations of the organisms living in their characteristic environments.

II. Investigations of the individual organism as an open and dynamic system, that is, its maintenance through exchange of materials and energy with its environment.

III. Investigations of the maintenance of the species, i.e. the problems of heredity, reproduction and development.

IV. Investigations of the organisms in their ecological setting.

V. Investigations of the historical continuity, i.e. evolution of organisms and their environments.

Examples of Investigative Projects

First Example

What insects live in water ?

A. Purpose of Investigation

To learn the kinds of insects associated with different kinds of places in an aquatic habitat.

B. Problems Involved

1. How to investigate ?
2. What materials will be required for investigations ?
3. What are the different kinds of places present in an aquatic habitat where insects are associated ?
4. What are the kinds of insects found in water ?
5. Do the insects live whole of their life in water or part of their life ? Which insects live wholly in water and which live only part of their life cycle ? And which part of life, adult or larva or nymph occurs in water?
6. Are the insects available round the year or in a particular season ?
7. Which insects are abundant ? Which are of average abundance ? Which are rare ?
8. Are there nocturnal insects and diurnal insects ?

C. Suggested Approach

1. It can be investigated by one student, one group or a class. A class may form a survey party which may be divided into several groups. Each group will

collect all kinds of insects, it can find in a single part of the water community.

2. Each kind of insect should be placed in different container.
3. Available data should be entered in field note-book then and there.
4. Two or three living specimens of each kind of insects may be kept in a container with water for further observations later on.
5. Collections should be done from various substrates such as rocks, living plants, bottom, under-surface, twigs and refuse.
6. For museum and future reference, two or three insects of each kind should be preserved and labelled with date, location and kind of substrate.
7. To know the seasonal variations of the insects living in winter, the above procedures may be followed at least once in each season of the year.

D. *Requirements*

1. Collecting nets
2. Containers
3. Preservatives

All these should be locally available or made.

E. *Conclusions*

Three useful items you have now assembled are :

1. A group of water insects whose names you may not yet know.
2. Specific part of a fresh-water community in which the insects live.
3. Seasonal variations of the kinds of insects living in water.

F. *Further investigations*

1. What steps will you now take to make these data useful to you and to others ?
2. What new problems have occurred during you present assignment which you want to solve ?
3. How are you going to tackle your new problems ?

Second Example

Nest Building Activities of a Solitary Wasp, the Potter Wasp.

A. *A. Purpose*

You are familiar with solitary wasps which frequent human habitations to build their nests. It is the female that constructs nest. The purpose is to investigate into the details of its nest construction and its object.

B. *Problems Involved*

1. To locate a solitary wasp in search of location to construct a nest.
2. What are the possible places inside your house where you can find mud-nests of the solitary wasps ?
3. How many cells are found in one nest ?
4. How many days does it take to complete a nest ?
5. What are the periods of its activities ?
6. How many visits does it make to the nest sites during the total period of nest construction ?
7. What kinds of visits does it make ?
    - (a) How many visits does it make to bring mud ?
    - (b) How many visits does it make to inspect ?
    - (c) How many visits does it make for the other purposes ?
8. What are the time intervals of the visits ? Are there any short intervals as well as long intervals ? What may be the reason ?
9. What does it do with each cell ; and when does it seal it ?

C. *Suggested Approach*

1. You will come across a female solitary wasp in search of nesting site in your own house or your neighbour's or in your school during May to September especially in July.
2. Locate one wasp.
3. Begin your watch with a time-piece and, to the second, you record your observations.
4. Whole day's watch may be necessary not to miss the

gap of its activities and you may miss your class for weeks together. This can be avoided by making a group of 6 to 14 students who can watch a day in turn.

5. Investigation requires no equipments, save, pencil, paper and patience.

D. *Results*

Record the results of your observations date-wise horizontally and types of activities column-wise.

F. *Further Investigations*

1. Do the nest-building activities differ in different solitary wasps ? In what ways ? In what types, size, shape, number of cells in nest, in location ?
2. Do different solitary wasps provide different prey in their cells ?
3. What are the uses of these prey ?
4. How long does it take for the adults to emerge out of the cell ?
5. How does development occur inside the mud-cell ?

Further Illustrations of an Investigative Project

(a) Rekha's Project

Encountering the Problem

Rekha was a tenth class student in one of the urban schools in Rajasthan. Her hobby was to cut or pluck flowers for decoration or display purposes. One day, the school gardener observed her while cutting flowers. He felt sorry for her for she 'allowed the cut ends of the flowers to be exposed to the air before placing them in water'. He asked her to 'cut the flower stems again while holding them under water before putting them in a vase'. Was not this the secret of keeping flowers fresh for a comparatively longer time ? Rekha was puzzled for neither she nor the gardener knew the reason. She talked naturally to her teacher about this chance observation who told her that the problem lay in the area of Ascent of Sap and Transpiration.

Effort at Seeking Information

Naturally, she went to the library and read all about ascent of sap, transpiration, structure and functions of stems, factors influencing rate of transpiration and potometers. She was still unclear about the problem which needed reformulation or specification at depth.

Formulation of the Problem

She reflected over this problem for hours. As a starting point, she hypothesized that the 'cut flowers that are placed in water immediately after cutting remain fresh for long periods ; and the flowers that are exposed to the air, for a long time, before being placed in water wilt earlier than the flowers treated in the first way'. Further, she also hypothesized that the period of exposure of flowers to air before placing them in water might also influence their freshness. Therefore, she formulated her problems as follows :

"Is the Rate of Water Flow through the stems of Plants significantly Influenced by the Air Exposure of the Cut Ends of Stem ?"

Designing the Experiment

Here again, she consulted her teacher and chose experimentally those plants which showed good rates of transpiration. Again experimentally, out of these plants, she selected these ones which showed the earliest signs of wilting. What about the potometer ? Here, her teacher did not oblige her. So she had to build her own potometer which took about a week's time. For this, she had to acquire skills in glass fabrication and operation of a high temperature torch. She also learnt how to read the potometer. After over coming these hurdles, she was now ready for conducting her project.

Maintaining the Records

She obtained blank sheets for this purpose. She knew the kinds of observations required to test the various hypotheses. She, therefore, drew appropriate tables on them in which readings could be recorded straight away. At the end of the experiment, she could easily tell about the name of the plant she had used, the type of treatment given to it, the date and timings when the various observations were made, potometer readings at different stages of the experiment, temperature, humidity, air pressure and light intensity. She also reserved some space for recording unanticipated observation, difficulties and hypotheses.

Keeping the Track

Her experimentation lasted for serveral days. She came across several interesting observations. For example, at the end of a few days, she noted that the 'plants that were cut in water had a more rapid rate of transpiration than the plant treated otherwise.' She was attracted by another problem, namely, variation in rates of transpiration in case of plants cut both ways during day time. She, however, preferred to stick to the original problem.

Reporting the Findings

She had collected lot of data to answer the problem with which she had started. Naturally, she had to write her project report. Her data indicated strongly that the 'plants that are cut while held under water show a more rapid rate of transpiration when compared with plants that are cut in the air'. This was true regardless of sufficient variation in temperature. She then presented her project report to her teacher under the following heads :

1. **Summary**
   - A. The topic or problem investigated.
   - B. The explanation of the problem.
   - C. The most important information gained from the investigation.

2. **Discussions**
   - A. Circumstances leading up to project.
   - B. Acknowledgement of help received from other people.
   - C. Methods used in investigations.
   - D. Tabulation of findings.
   - E. Conclusion and reasoning upon which it is based.
   - F. Argument or suggestions to other workers.

3. Appended Materials

Drawing, photographs, graphs, calculations, supporting the project report.

She got another opportunity to talk on her project to other science teachers as well as science club members of other neighbouring schools. She won recognition.[2]

Additional Problems for Investigation

She was now delighted that her project had shaped well. She had won recognition from teachers and her mates. But still, her project raised several problems.

1. Do the rates of transpiration also vary in other plants with the change in time of day ?

2. Does the transpiration rate in cut flowers have definite period ?

3. What is the best temperature at which to keep cut flowers fresh longest ?

4. What are the quantitative relationships of transpiration rates to humidity, temperature, and light ?

It is only under the circumstances that science solves one problem and creates a few more. They await their turn to be mastered. It is how the Mastery of Mind over Natural Environment proceeds forward in science as human adventure. For individuals with limited lives, science thus becomes a life time pursuit.

(b) Arun's Project

He, like Rekha, also encountered the same problem in his day to day classroom learning. He was not much impressed by his teacher's demonstrations. He asked a mechanic to show him the pressure gauge and explain its working to him. He remained dissatisfied with the mechanic's explanation. He could not borrow the needed equipment from his teacher because he had not formulated his problem clearly. He made extensive readings and finally decided to construct several pressure measuring devices. But to his disappointment, not a single device really worked. He finally hit upon the idea of constructing a monometer. Air bubbles interfered too much when he put mercury into it. He used graph paper for measuring the rise of the level of mercury. He found the root pressure one atmosphere. His efforts were recognized and he won a prize.[2]

(c) Khan's Project

Again interestingly enough, Khan also encountered the same problem. Only the circumstances were different. He read about this problem in plant physiology as well as physical chemistry texts. Particularly speaking, he sought information on osmosis, capillarity and accidentally, encountered new information on electro-osmosis and streaming potential. He was too much excited about the sap-rise phenomena, but no book gave him the satisfactory reply. He, therefore, decided to tackle this problem himself. He discussed his problem with one of the university professors. The university professor also got interested in his problem. Khan, therefore, after lot of thinking, developed the following broad hypothesis: The Auto-electro-osmosis Hypothesis:

> Assume a small vertical tube in a tree—a tracheid. Assume the tracheid is filled with water. The water diffuses outward through the tracheid walls. The diffusion produces an electrical potential difference between the inside and outside of the tube wall (streaming potential). Suppose the diffusion is more rapid at the top of the tube, the potential difference will be greater at the top. If this is true, a potential difference will exist between the inside top and the inside bottom of the tube. From the known phenomenon of electro-osmosis, an upward liquid flow will be initiated in the tube by this potential difference.

It was too broad a hypothesis. He, therefore, further subdivided his main problem:

(a) How is the electro-osmotic flow rate affected by the magnitude of the potential difference?

(b) How is the streaming potential affected by the rate of osmosis?

(c) How are streaming potential and the electro-osmotic flow rate affected by the nature of the membrane through which the flow occurs? [The equipment was designed and the observations were recorded properly. Many side questions appeared which, of course, did not distract Khan. Like Rekha and Arun, Khan's efforts were also recognized. He also won a prize.[2]]

Here, it is a good example where the same problem was seen and tackled differently by three different individuals. They made extensive readings as well as read articles in order to obtain sufficient background information about the problem. They thus had the vague idea about the unknown territory of the problem. They were compelled to think and formulate the problem as sharply as possible before they could hope to obtain practical help from their science teachers. They had to drop part of their co-curricular activities for the problem required lot of concentration on their part. They did not get the readymade equipment. They had to design and fabricate it themselves. Incidentally, they also learnt how to keep it neat and safe. They also learnt that in the execution of a project, outside help becomes necessary. Experts are too willing not to refuse help provided they are convinced about the background work already done by the projecteers. They also learnt that moments of frustrations must be mastered in the interest of the problem for sooner or later new insights into the problematic situation appear. Their sincere efforts resulted in the successful execution of the projects which in turn won recognition, admiration and award. The fourth projecteer could read their reports and even attempt to integrate their individual findings. Or alternatively, he could formulate his hypotheses more sharply as well as fabricate a more sensitive equipment. If he were a bit more imaginative, he could attempt to interpret their recorded observations quite differently. This leads to controveries. History of science is full of such intense controversies. Controversy is not a bad thing in science. On the other hand, it is instrumental in generating new scientific knowledge. Controversies in science arise when scientists offer different hypotheses to answer the same question or observation. The young projecteers also need experience in handling controversial problems. This is an educative experience for them for controversial problems in science are not decided by counting the number of noses. Those who count have to first collect evidence in an unprejudiced manner. The correct minority view may be resisted for some time but it is bound to be accepted firmly in the near future. There is some dogmatism in science but also lies at its heart what we call 'innovation'. In short, all the projecteers are going to benefit in one way or another by carrying out investigative problems or projects. They will gain new knowledge and skills as a result of having had a close look at some selected natural phenomena, opportunities for practising the various processes of science, and personal experience of utter ecstacy and frustration. Lastly (but fortunately), it is also a tryout experience for those who wish to attempt advanced scientific work later on as whole time working scientists.

Other Examples

The Science Youth Project did not stop only at the Sap Rise Phenomenon. They developed ideas for investigations on several topics like Aging and Life Span ; Artificial Clouds ; Bouncing Balls; Coal, Coins, Combustion, Corrosion, Dielectrics ; Earth Quake Waves ; Earth works ; Electrolysis ; Fluid Jets ; Freezing Point Depression ; Heat Absorption in Plants ; Lubricants ; Minerals ; Ozone ; Parascience ; Photosynthesis ; Population Studies ; Poultry Farming ; Respiration, Saliva ; Seed Germination, Soft Drinks ; Starch ; Studies on Inactive Life or Life in Suspension ; Synthetic Rubber ; Tooth Decay ; Toys ; Visual Inversion ; Water Rocketry ; Wells ; Wood ; and many others (2). They also saw to it that most of the investigations were within the physical resources of the school as well as within the mental capacity of the vast majority of children. They gave to these investigations vast content and imaginative forms. G Guru so eloquently put it, "The student should constantly keep in mind that there is the possibility of alternative procedures." "He should be always in search for new problems and design his own experiments to investigate them." Let us now reproduce below the following additional examples which contain unsolved problems for consideration at the hands of our projecteers :

1. Aging and Life Span.
2. Lubricants.
3. Population Studies.
4. Soft Drinks.
5. Tooth Decay.[3]

1. Aging and Life Span

As organisms become old, they appear to lose their vigour and die. The maximum length of time an organism lives, its life span, is one of the characteristics that varies from species to species. The life span of man is approximately 115 years. The toad has a life span of 35 years, while the rat lives only 4½ years.

Aging is a complex process with many factors contributing to the causes. Man's life expectancy (average length of life) varies from one part of the world to another. Wild birds in the field live a considerable shorter time than the same species of bird kept in captivity. Here a contributing factor appears to be the hardship of environment. However, under carefully controlled laboratory conditions, planaria (a kind of worm) that are alternately starved and fed survive longer than those that are steadily fed. The regularity of intervals between feedings may be a controlling factor but other factors such as the quality of food, manner of feeding, temperature of the atmosphere, cannot be ignored. In order to test the effect of one of these variables, an investigator has to control all other variables.

Animals such as earthworms, pigeons, hens, turtles, and insects such as cockroaches and butterflies may be used by students in their experiments. The study or aging and life span in the case of man is limited to such things as surveys of family history and the examination of individuals for physical characteristics of the aging process.

In testing factors that control or influence the life span of an organism, it is better to study specimens having short life cycles. Fruit flies and water fleas are better subjects than turtles and pigeons. Consider the following problems for investigation :

1. What effects do the alterations in diet, temperature of body, light, environment, or climate have on the life span of an organism ?
2. Do the offsprings of younger parents tend to live longer than the off spring of older parents ?
3. Is the life span of one sex greater than that of the other sex ?
4. Does the size of an organism affect its life span ?
5. Does the old age of an organism affect its mental efficiency ? Is there any truth in the phrase with reference to man and other organisms that "you cannot teach an old dog new tricks" ?

6. What physical changes occur as organisms become older? What physical changes occur in organisms after death ?

7. Do long-lived parents produce long-lived progency? Are there physical characteristics of a given organism such as the annual rings of a tree and the weight of lenses in the eyes of a rabbit that enable one to determine its age ?

2. Lubricants

Industrial machinery would soon slow and ultimately stop if the supply of lubricating oils became depleted. Every piece of machinery that moves, from automobile engines to wrist watches, requires proper lubrication. Recent commercial developments feature motor oils that maintain a given viscosity over a wide temperature range and automobiles that can go 4,000 miles between oil changes.

1. Can old oil that has been drained from automobile crankcases be reprocessed for use, or is it really worn out?

2. Do lubricants vary in effectiveness if the part to be lubricated is magnetic ?

3. Does water, or any other substance, cause a noticeable decrease in the action of a lubricant ?

4. How are the lubricating properties of oils affected by high pressures ? Is the same effect noted for solid lubricants such as graphite and lead oxide ?

5. Does the phenomenon of thixotropy (liquefaction of a gel by vibrating forces such as shaking and ultrasonic waves, and its setting again on standing) have importance in the all-temperature oil ?

6. Is the effectiveness of a lubricant a function of molecular-size, weight, or of molecular geometry ?

7. How do the coefficients of friction between various objects change with lubrication ?

3. Population studies

The world human population is increasing at an astounding rate. If the present annual rate of approximately two per cent continues, there will be more than six hundred crores people on earth by the year 2000—twice the population of 1965. The explosion of population is mainly the result of the decrease in death rate due to the increase in medical knowledge as well as an increase in the birth rate. For instance, in India, the death rate fell from 27.4 (per thousand) in 1949 to 23 in 1963. The birth rate rose during the period from 39.9 to 42, and consequently the total population increased by 22.3 per cent.

Population dynamics is very much a part of biology. All organisms have the capacity to increase in numbers geometrically (theoretically, houseflies could fill the visible universe in just a few years). But no organism realizes its full reproductive potential as there are numerous limiting factors in the environment that prevent uncontrolled growth. These limiting factors include food, oxygen, light, disease, war, predators, space, and toxic effects of body wastes. The biologist can learn much about general population growth through laboratory experiment, where the limiting factors are controlled.

1. What percentage of the total human population is constituted by females, and what percentage by males, in your beat (locality chosen for survey)?
2. What is the percentage of literate people in your beat?
3. How many boys and girls are receiving education at various stages? What is their percentage of the whole population?
4. What is the change of population in one year in your beat? From these figures, can you estimate the change in total population?
5. What are the common diseases among the members of your beat?

4. Soft drinks

Carbon dioxide gas is dissolved in almost every soft drink. The solubility of carbon dioxide is directly proportional to the amount of pressure applied. Carbon dioxide forms carbonic acid in water solution. When the pressure inside the bottle is reduced by removing the lid, carbonic acid decomposes. Carbon dioxide then bubbles through the beverage and passes out of the bottle.

The degree of carbonation differs from one brand of soft drink to another. Such comparisons should be made for a fixed volume of beverage. Permanence of carbonation might be estimated quantitatively by measuring the rate of carbon dioxide released at a standard temperature and pressure.

1. After being opened, do certain soft drinks retain their carbonation longer than others?

2. Is there any difference in the degree of carbonation of various soft drinks?

3. Is there any negative catalyst that will slow the decomposition of carbonic acid to carbon dioxide and water? To be useful, the substance obviously could not be toxic.

5. Tooth decay

Tooth decay usually occurs as a result of the bacterial fermentation of carbohydrate particles that are left between the teeth after eating. Fermentation is so rapid that generally within an hour corrosive acid can be detected. The acids are produced by bacteria that grow in a soft deposit (called dental plaque) that surrounds the teeth. The first action of acids takes place on the inorganic substances of teeth, enamel (outer coat of teeth), and then starts, dissolving dentin and pulp (organic portion of teeth).

The large number of bacteria in the mouth does not necessarily indicate the possibility of tooth decay. Lactobacilli, acid—producing bacteria, have been found in the mouth as early as six months before actual decay in a tooth has started.

1. How strong are teeth? How much force can a tooth support vertically? Horizontally? What extremes of temperature can a tooth endure? How do the acid resistances of teeth compare?

2. How do habits of smoking and chewing petals affect the multiplicity of the bacteria in the mouth?

3. How efficient are the different available brands of toothpastes in stopping tooth decay? Suggest a good brushing technique.

4. What are the causes of good dental health in persons who are free from tooth decay? Is there any hereditary explanation for this?

5. How does the population size of bacteria in samples of saliva fluctuate with the kinds of food a person has recently eaten?

6. How do the bacterial counts and pH of the mouth of one individual vary with health, age, and time of day?

7. What changes occur in the tooth as a person becomes older?

8. What tooth diseases can be observed in animals other than man?

9. Is there any truth in the advice not to take cold things after hot things or vice versa because this might damage the teeth (*3*)?

Concluding statement

What is happening here? The pupils' attention is being directed towards certain natural phenomena with which they have had first hand encounters. They are asked to reflect upon these experiences and thereby suggest suitable answers to various questions through observation, experimentation and speculation. In this, they are expected to select a fruitful problem for investigation, suggest a suitable strategy or procedure to carry out the investigation effectively, to execute the strategy as postulated, to record observations and tabulate them, to arrive at the results and appraise them critically and lastly, to relate one's results with the results of others, past and current. The successful solution of one problem gathers momentum at the school and in its train, several students, at their own level of functioning, select problems, which match excellently with their talents and tools.

It is quite possible to work out the various units of instruction included in the syllabus in such a way as to formulate and reformulate, more and more productively, a good number of project ideas having a wide appeal to children. Projects thus formulated will go a long way in generating new knowledge and experience for the pupils much beyond their subject. It is just possible that a few of the pupils may stumble against certain original problems engendering intense curiosity as well as may discover original facts, like Galelio, that the period of simple pendulum depends strictly on the length of the pendulum, before he had entered the university. It hardly matters if they discover new facts with wrong interpretations for it was found much later on that Galelio had discovered moon rather than any other hitherto unknown planets. The investigative features already mentioned in the first chapter may be only considèred suggestive rather than prescriptive for the very reason that the Authoritarian Principle does not work in the domain of science. Secondly, unnecessary and unimaginative restrictions with a view to get quick results kill the very soul of science.

Lastly, science teaching in our country, despite our best efforts to improve it, is in a very bad shape. Our students pass their examinations but they are not all familiarized with the nature of scientific enterprise. We thus fail to build quality into our science teaching for the very reason that innovation and research are not built into it. Investigative projects thus show great promise in overcoming the main deficiencies of science teaching. Our experience at the science youth project clearly demonstrated that an investigative project need not be very costly for majority of pupils. If carried out in the right atmosphere and spirit, work on the project is a transforming experience both for the students and teachers in posing problems gradually or otherwise at depth and seeking their solutions more and more experimentally. We can thus succeed to impart training in scientific methods using reasonably cheap materials. If suitably bent, the completed projects can supplement and enliven day to day classroom teaching. If carefully cultured and nurtured through proper guidance and follow up, investigative projects will surely turn out to be powerful Impact Nucleis ; away from stressing memory in learning science with the inherent potentiality to change the scientific and technological face of a tradition bound society having 'two big majorities of the poor and the young' (Indira Gandhi).

6. The Variable Illustration of Some Specimen Projects

Undertaken by Some Selected Science Teachers and Science Talent Competitors

I am really very happy that you (his uncle) are still interested in the little things I am doing and working on, even though we could not see each other for a long time and I am such a terrible lazy correspondent. I always hesitated to send you this (First paper concerning the investigation of the state of aether in magnetic fluids) attached note ; because it deals with a very special topic, and besides it is still rather naive and imperfect, as is to be expected from a young fellow like myself. I shall not mind at all if you do not read the stuff ; but you must recognize it at least as a modest attempt to overcome the laziness in writing which I have inherited from both of my dear parents.

As you probably already know, I am now expected to go to the Polytechnic in Zurich. However, it presents serious difficulties because I ought to be at least two years older for that. We shall let you know in the next letter what happens in this matter.

—Albert Einstein

Every child of this nation is very notorious by nature for breaking and deforming the things of his household. This is the common experience that any defect or breakage in the household material (e.g. Radio, Watch, Sewing Machine, etc) is attributed to be done by the youngest member of the family. This is true even now. Today's younger generation is tomorrow's great men not only of his own nation but of the world. The political leaders Dr. Rajendra Prasad, Dr. S. Radhakrishnan, Dr. Zakir Husain; the eminent scientists of world-fame: Sir C. V. Raman, Noble Laureate, Dr. J. C. Bose, S. Narlikar; the famous literary workers: Shri Rabindra Nath Tagore, Munshi Prem Chand, Shri Maithili Saran Gupt were children of their own times and I am sure that they too would have been reprimanded by their parents in their childhood. In my view, a child is a true scientist. He tries to learn something by breaking or deforming the things of his house and his knowledge increases with his age. The young blood tries to know "How and Why" of every mechanism. Yesterday's naughty child is today's young scientist.

—A Projecteer

Born in a family of Engineers, from my childhood, I was interested in studying the basic principles of Science and Engineering. The Engineers in my house used to kindle my curiosity and also provide the answers to my numerous doubts and questions. One thing that engaged my attention often was the rusting of iron. As a child when I first purchased my gleaming white mathematical set of instrument box of protractors, etc., I was soon to discover that in a short time the white appearance vanished giving place to a black image which I later learnt was rust. I could not then understand why the celluloid protractors etc. which my friend had purchased never changed colour. We were then living near the sea-coast. During the next few years, we moved to the interior where the climate was dry and the new protractor I bought did not turn black so soon as the one I had while living near the sea-coast. To all my innumerably questions, my father calmly told me that this phenomenon is known as CORROSION or RUST FORMATION. He explained that this happens only to metals like iron etc., and will not affect the plastics or celluloid. I also understood that this phenomenon will be more pronounced in coastal areas where the air is more humid.

—Another Projecteer

As a child I was always fascinated by the display of colours in nature. The bright blueness of the sky, the various colours of the rain-bow, the changing colours at the sun-set and many more attracted me very much and I used to watch their brightness for long hours. I did not know at that time how these colours were produced. When I grew up, I began searching the cause of these colours of nature but I found no satisfactory answer. Gradually, when I became a college student, and as I have a hobby of reading books, especially, on various branches of sciences, I found answers to my puzzle. For instance, I now know that the blue colour of sky is due to the scattering of light by very small particles of organic matter which float in the air. I also know that white light is composed of seven colours and that the colours of rain-bow are produced by tiny particles of water acting as prisms. The red colours both at the time of rising and setting sun are again due to longer wave-lengths reaching us in greater amount. Thus, at the source of all these colours is the fact that white light is made up of seven colours with different wave-lengths. Violet has the smallest wave-length and red has the longest wave-length.

But inspite of all this knowledge, a much more difficult problem, which attracted my mind, could not be solved by me, and haunted me whenever I thought of it. The problem was why certain matches used during Diwali festival (a festival celebrated by Hindus during which people use several kinds of fireworks) produce brilliant colours when lighted ? Although I knew what makes them burn and produce a flame, I did not know what made the flame coloured. I, therefore, selected this problem for my project report so that with the help and guidance of my chemistry teacher, and my own father, who is also a chemist, I could solve the problem and know the correct answer.

—Another Projecteer

During the last summer vacations, I happened to be at my maternal uncle's house in Aligarh and there I had the occasion of drinking a bad quality water in the sense that it was quite saltish as compared to the water that I have been using at Roorkee since birth. There is a marked difference between the two. One is sweet and cold ; whereas the other is saltish and warm. This set me thinking that probably the bad quality of water is due to the presence of salts contained in it. As a matter of fact, all ground waters (well waters) contain salts carried in solution and their quality largely depends upon the amount and composition of these dissolved solids.

—Another Projecteer

Once I was washing my clothes. Making the soap solution, I saw many bubbles. Those days the chapter of surface tension was being taught in my class and thin soap-films were discussed to obtain the surface-tension of soap-solution. When I saw these soap-bubbles, I at once remarked and thought about the thickness of the surface of the soap-bubbles. I was much pleased when I got some ideas about this funny project in a Physics Book published by the N.C.E.R.T. In that book, for finding out the thickness of the surface of soap bubbles, ideas were given but they were in brief and it was not possible for me to put them practically. I was thinking that the thickness of the surface of the soap-bubble may be in molecular order. In the above book, it was written that one drop of stearic acid, on water, forms a layer with an area over 50 sq. cm. Dividing this area into the volume of the stearic acid, dropped in water, we get the thickness of the layer of the stearic acid. This value as the book suggested was 20 angstroms.

—Another Projecteer

I had been reading about the simple Voltaic cell from class VIII, but had neither read about (1) the strength of sulphuric acid used in this cell, nor (2) the effect of different electrolytes on the common elements, nor (3) the effect of different groups of common elements on the specific electrolyte. These questions were giving me anxiety for some time, no text book showed me the correct answer to solve my problems. As a candidate for the SCIENCE TALENT SEARCH EXAMINATION, I took up these problems and set to work.

—Another Projecteer

While riding bicycle, as I fast as I can, with the wind rushing against my face, I have often wanted to know how fast I can pedal my cycle. Once sitting beside the driver while making a long journey by car, I observed that as the car moved faster, the wind brushed past my hand outstretched through the window, exerting a greater force on it. Then I realised that this principle might be utilised to measure speeds of vehicles by a simple instrument and this prompted me to prepare this project.

—Another Projecteer

Introduction

Projects, simple or complex, small or big, fundamental or applied, and cheap or costly are our great educational resources inhering open objectives with sight on quality commensurate with international standards, for they provide opportunities to the projecteers, each according to his greed, to learn, to handle firmly, evolving scientific concepts, as well as to acquire needed skills during problem solving, largely speaking, unaided. They not only experienced science and processes of science first hand, but also what it actually means being patient, curious, preserverent, openminded, keeping fingers crossed, and being able to change opinion in the light of new evidence. These intellectual and personality plus factors have to be earned while working on the project rather than to be taught conventionally in our classrooms as part of advisory work. Exposure to Fundamental Scientific Phenomena is necessary as the first prerequisite but not sufficient for the 'Journey of a Thousand Miles' which begins for some one only when he takes the first step or plunges oneself partially into the problematic situation to fish something out, whatever the hazards, 'with no holds barred'. Interestingly enough, at the unknown frontiers, one occasionally arrives at the truth either by following right track or falsehood by following the originally conceived right path. For the scientific adventurer, past knowledge is both an asset and a liability. It is an asset or an useful guide for one can then with confidence dogmatically pursue one's idea right upto the end of the limb in the face of initial failures. It is a liability, when gone into head firmly, it successfully restricts the incoming of fresh approach and new insight very necessary to discover something new. Project work, therefore, opens up new frontiers of knowledge for those who have the intellectual accumen and the requisite physical stamina to cut the problematic situation at its knotty point imaginatively. The whole field of science then becomes fun and fascination in which they try hard to discover an unknown pattern (logically sound, aesthetically beautiful and emotionally satisfying) or try hard to obtain a clean and neat solution to a complex problem. They do not end here. They continually ask a new question or change the perspectives of age old questions. More, W. Cresap Jr. perhaps talked of this when he said, "It is the scientists who now face the great frontiers : theirs is a unique world-wide fraternity dedicated to the mystery of nature ; not the mastery of man : in them we find the vision and spirit and purpose which have constituted the elements of leadership in the past". It is only then the young projecteers later on as a result of undergoing Project Experiences that they will acquire 'fresh, unorthodox, nimble, and vibrating minds' (Warren Weaver). There is a lesson, as clear as the writing on the wall, for those who participate in a big way in teaching and administering of science education in our country. Whatever the amount budgeted including international collaborative efforts for building quality into science education, India, the second giant in numbers, cannot capture even part of the international leadership in an environment in which our youngsters do not hesitate to copy, stab invigilators, and cook results to get more marks and better positions of employment. In turn, science will punish them cruelly. Our total contribution to our global scientific and technical knowledge every year comes out to be less than 1 per cent (D.S. Kothari). These are not at all the fair prospects for a country like ours to go up in the comity of advanced nations. It is no wonder then that we continue to be rich in resources but poor in intellectual and economic efficiency. (The recent atomic bang has been our very pleasant surprise and exciting achievement under very unfavourable conditions.)

Analysis of projects

It is this concern, hope on hope, shared by some of us at the Regional College of Education which led to the development of two experimental projects, namely, The Mobile Science Show and The Science Youth Project, now dead for all practical purposes. Under the imaginative leadership of Prof. A.N. Bose, part of the experiences gained were woven, without incurring any extra expenditure, in the training of science teachers in the four year courses (now raised to honours standard). The writer did not stop at this but had a look at another mine of ideas, the Department of Science Education in the N.C.E.R.T. There they receive thousands of science projects (and burn them in the succeeding year for they have no storage space !) as part of the Science Talent Search Examination. Dr. M.C. Pant, Dr. K.N. Saxena and Shri Ved Rattan sent me, in two batches, over 500 randomly selected projects for the so called penetrating analysis. They, on reading, turned out to be jewels in the dust. They presented a standard of achievement which I had little come across during my teaching sojourn in England. A firm belief began to grow in my mind that our lads can do anything even under mediocre leadership which most of us unknowingly provide to them. What was just sufficient was to 'Ring the Bell' in the words of Bacon. I searched for a definition of project which even I could not find in literature and develop, despite the availability of several projects, at my command. I began to analyse each and every individual project, a job which is as difficult as to determine a common pattern of behaviour in a group of diverse cranks, in terms of the following variables :

(1) Get up
(2) Title of the Project for Areas in Science Covered
(3) Statement of the Project
(4) Type of the Project : Investigative or Non-Investigative : Historical, Essay, Bookish or Repetitive
(5) Selection of the Project. How did it Originate ?
(6) Materials Required (Given or not Given)
(7) Introducing the Project (Manner)
(8) Aims of Investigation
(9) Survey of Relevant Literature or Review Literature
(10) Method of Procedure or Design of Experiment
(11) Relevant Theoretical/Mathematical Treatment Given (If challenged, it becomes the project itself)
(12) Formulation of Hypothesis
(13) Recording of Observations
(14) Presentation of Data
(15) Conclusions Drawn from Data
(16) Discussion of Results, Sources of Errors and Precautions to be Observed
(17) Nature of Difficulties Encountered and Overcome
(18) Limitations of the Project
(19) Brief Summary/Abstract/Synopsis Given
(20) Additional Problems for Investigation Suggested
(21) Application of the Project
(22) Cost of the Project
(23) Time Required to Complete the Project
(24) References Consulted and Suggested
(25) Acknowledgement, Nature of Help Sought and Received.

Other factual details regarding the number of words, observations made, diagrams (including photographs) drawn, number of experiments performed, number of factual mistakes made, and any other specific characteristics of the project under study were also noted.

Evaluation of projects

Each project was first read as a whole. Its strengths and weaknesses were recorded. Then the entire project was analysed in the context of the above-mentioned variables, one at a time. The analysis was revealing but many of the variables could not be objectively ascertained. Secondly, no general conclusions could be drawn because the projecteers had been only given little information in regard to what was expected of them. Thirdly, no value judgement on the analysis of the projects could be made on the basis of inadequate information and inexplicit aims and objectives of project work. Fourthly, it turned out to be a deceptive exercise when various aspects and phases within each aspect for all projects were tabulated and added. Lastly, in the absence of any past instructions regarding the selection and execution of the project, it became very difficult to discern a common pattern. Even in my head, what constitutes first class project work began to vanish. The solution of the problem lay in sleeping over the entire bunch of projects or in thinking like a stupid chimpanzee, before the moment of insight, sitting on a box quite away from the goal. It was, therefore, decided to lay aside the findings of the analysis of the project reports ; and instead develop a backdrop against which each project could be observed and evaluated. It is just like defining a Hindu who is not a Muslim, Christian or Parsee. The ten projects, largely speaking, reported raw in this chapter adequately sample the philosophy of project work, that is, the act of making task oriented opaque situations transparent through scientific methods.

Procedure for studying these projects

Both students and teachers are asked to read these projects one at a time carefully and note each one's strengths and weaknesses. This exercise will give them a vague idea of what it means of conducting a tolerably good project for immediate recognition. In this respect, the following suggestions are made :

(i) Read these projects carefully. Determine thus their main strengths and weaknesses.
(ii) Take the weaknesses one by one. Think how would you remove them had you been in their position ?
(iii) Study the aims of the investigation. Has each one of them been fulfilled ?

(iv) Read observations and conclusions made upon them carefully. Can you suggest alternate procedures or hypotheses and even interpretations ?

(v) A given project raises more problems than it answers. Make a list of such problems around some of the projects which directly appeal to you most.

(vi) Select any one of the problems which interests you most. Read more about this problem. And then discuss it with your friends, relatives or even teachers.

(vii) If you fail to select one, either go back to the last chapter or the succeeding one for the survey of more Project Ideas.

(viii) If again you fail, read your text-book carefully. Challenge any one of its statements. For example, if you read that a magnet always points in the north south direction, challenge it ? Does a magnet always point exactly in the north south direction ? Is it possible to have magnet with one or more than two poles ?

(ix) Repeat a project and improve upon it, if possible.

(x) Even if you again fail, then try a non investigative project, namely, essay on any one of the recent advances in science or historical episodes.

It is only in one of the above-mentioned ways that you can hope to develop a life long friendship with science.

Some Illustrated Specimen Projects

Section A

Physics :

(1) Measurement of Viscosity of Various Liquids
(2) A Simple Apparatus for Verifying Boyle's Law
(3) Wind Mill
(4) How to Find out the Thickness of the Penetration of Ink on a Writing Paper

Section B

Chemistry :

(5) Determination of Molecular Weights of Volatile Liquids

(6) Paper Chromatographic Separation of Copper and Iron
(7) Acidity of Lemon Juice

Section C

Biology :

(8) Micro Organisms Present in Gut of Frog
(9) Effect of Some Acids on Germination and Growth of Some Seeds
(10) A Study of the Effect of Growth Regulators on Rooting of Bryophyllum Calycinum

Section A

PHYSICS

1. Measurement of Viscosity of Various Liquids

Problem

To arrange different liquids according to their viscosities.

Introduction

When a liquid flows there exists frictional force between any two layers of the liquid which retards its flow. This force is known as 'viscous drag' and the property of the liquid is known as 'viscosity'. When a piece of a denser material falls through a liquid, the viscosity plays a vital role imparting to the piece a terminal velocity which is constant. C. G. Stoke studied this problem ; and from his studies came Stoke's Law in which the viscosity of the liquid and the terminal velocity of a falling spherical ball were connected as follows :

$$n = 2/9\ g\ (p - d)\ a^2/v$$

where n = coefficient of viscosity of the liquid
g = acceleration due to gravity
p = density of the ball
d = density of the liquid
a = radius of the ball
v = terminal velocity of the ball in the liquid.

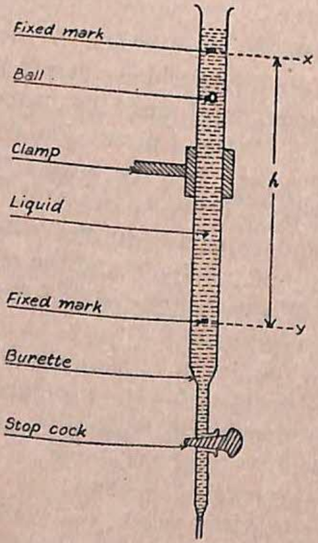
We can extend this idea to compare the viscosities of different liquids by letting a ball of some denser material fall through these liquids. It is clear from the above relationship that the viscosity of a given liquid is inversely proportional to the terminal velocity (which equals distance divided by time). Or, the viscosity is directly proportional to the time taken by the ball to fall through a fixed height. In simple words, this argument shows that more time taken indicates a more viscous liquid ; and vice-versa.

Problem

To arrange the following liquids according to their viscosities using Stoke's Law: (a) water (b) mobil oil (c) kerosene oil (d) glycerine (e) alcohol (f) coconut oil.

Material

(i) A burette nearly half meter long.
(ii) A burette stand.
(iii) A stop watch.
(iv) A steel ball (bearing).
(v) A powerful magnet.
(vi) Liquids mentioned above.



Viscometer.

A burette (50 cc) is fixed vertically in a burette stand. The burette is filled with one of the liquids. A small steel ball (3.2 mm diameter) is dropped through the liquid. For some time, the speed of the ball will go on changing but after some distance it will attain a terminal velocity and this terminal velocity will then remain constant. To find out the terminal velocity, the time taken by the ball to fall through a fixed distance, is noted. The time taken by the ball to fall through the distance between two fixed marks (0 and 50) on the burette is recorded with the help of a stop watch (1/10 sec.). With the help of the magnet, the ball is then lifted from the bottom of the burette well above the upper mark and let go. The time of fall between the fixed marks is again recorded. This process is repeated a number of times and the mean time is determined.

The burette is then cleaned and filled with the next liquid and the same procedure is repeated in order to find the mean time of fall of the same ball between the same fixed marks.

In this way, the times of fall of the ball through the same height in all the liquids given are determined.

Sample number	*Liquid*	*Distance fallen (xy)*	*Time taken (sec)*	*Mean time (sec)*
1		*2*	*3*	*4*
1	Glycerine	xy	11.2 11.2 11.3 11.2	11.2
2	Mobil oil	xy	4.5 4.6 4.5 4.5	4.5
3	Coconut oil	xy	1.8 1.7 1.7 1.6	1.7

1		*2*	*3*	*4*
4	Water	xy	0.3 0.4 0.3 0.3	0.3
5	Kerosene oil	xy	0.5 0.4 0.4 0.4	0.4
6	Alcohol	xy	0.6 0.6 0.7 0.6	0.6

Interpretation

The data suggest that the above liquids can be arranged in their decreasing order of viscosity as follows :

1. Glycerine
2. Mobil oil
3. Coconut oil
4. Alcohol
5. Kerosene oil
6. Water.

Conclusion

The given liquids have been arranged as desired.

Limitations

1. Stoke's Law is applicable more successfully for low terminal velocities whereas in the case of liquids like water, alcohol and kerosene oil, the ball falls too quickly through the liquids, for its time of fall to be measured accurately by this method.
2. If the liquids differ in their viscosities by a small amount, then Stoke's method does not give desired results for a small height of fall.

Problems to be Investigated Further

1. To investigate the effect of the size of the ball on terminal velocity.
2. To investigate the effect of temperature on viscosity.
3. To investigate the effect of magnetic and electric fields on the viscosity of a liquid.

2. A Simple Apparatus for Verifying Boyle's Law

Introduction

The verification of Boyle's Law has become quite difficult to do with the help of a Boyle's Law apparatus because of the following reasons :

(a) It requires about one and a half lbs. of chemically pure mercury costing about Rs. 200.00 which is very expensive for a school laboratory.

(b) The apparatus is handled by a number of students and many of them get the mercury spilled in the laboratories due to their careless handling. This causes a tremendous loss to the laboratory. Sometimes, the apparatus remains unservicable for a long period, as the supply of mercury, due to its dearness, becomes very limited.

(c) The mercury available in the market is not chemically pure. This impure mercury leads to wrong results as it sticks to the sides of the apparatus or sometimes oxidizes at the two surfaces of the mercury in the closed and open tubes.

The problem

Is there any device which can help us to prove Boyle's Law but without the use of mercury ?

Suggested improvisation

(a) If an intravenous syringe of about 50.0 cc capacity is used and an air column is enclosed in it, then the Boyle's Law can be verified : for the increase of pressure on the piston will increase the pressure on the enclosed gas which results in decrease of volume of the gas at the room temperature, i.e., at the constant temperature.

(b) The Boyle's Law, derived on the basis of molecular theory of gases, can also be proved, because the number of molecules present in a certain mass of the gas remains constant.

(c) The Boyle's Law with respect to the density of the gas can also be proved.

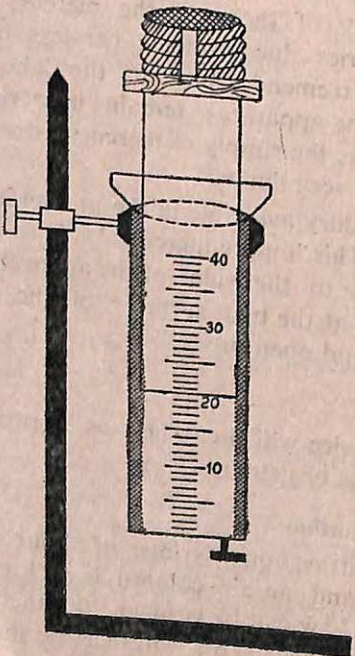
Materials required

(a) A medical hypodermic syringe of 50.0 cc capacity used for intravenous injections.

(b) A wooden circular cap for the upper end of the piston.

(c) About one dozen slotted weights of ½ kg each.

(d) An adhesive cement called 'Araldite'.



Boyle's Law apparatus.

Procedure

(a) First of all, a circular wooden cap with a groove to fit the upper end of the piston is prepared to get a flat platform to support a number of ½ kg weights.

(b) Smaller outlet of the syringe was sealed using a special adhesive cement called 'Araldite' manufactured by Ciba Ltd.

Observations

(a) Using the apparatus shown in the figure, after the piston was greased with glycerine, the pressure of the gas was measured in terms of weights of ½ kg each. The volume was recorded directly from the graduated syringe.

(b) The observations were taken according to the table given below for the varied positions of the piston and the graph showing the relation between pressure and reciprocal of volume was drawn.

S. no.	*Pressure* (kg/cm^2)	*Volume* (*cc*)	*1/Volume* (cc^{-1})
1	1.6	48.0	0.0208
2	2.1	45.0	0.0222
3	2.6	42.0	0.0238
4	3.1	40.0	0.0250
5	3.6	39.0	0.0256
6	4.1	37.0	0.0270
7	4.6	37.0	0.0270
8	5.1	34.0	0.0294

Note : Atmospheric pressure at AJMER was 1.1 kg/cm^2. Using the above observations, the graph between pressure and volume was drawn.

Interpretation of data

(a) The graph of the weight in kg varies reciprocally to the volume of the enclosed gas which clearly shows that within experimental error, the points fall on a straight line. It shows that Boyle's Law is quite true, i.e. $P \times V = \text{Constant}$.

(b) It confirms also the molecular model of a gas as suggested in PSSC physics text book; as the mass of the enclosed gas is taken as fixed according to the Boyle's Law, a graph between number of $\frac{1}{2}$ kg weights and N/V (where N is number of molecules in the amount of gas taken for the experiment) will also be a straight line, because 'N' remains constant.

Limitations

Two or three points deviate from the Boyle's Law curve. It might therefore appear that, the verification of Boyle's Law is somewhat fortuitous. However, a closer examination of the apparatus revealed a slight leakage. Hence, it would be reasonable to conclude that the departure from the Boyle's Law is not so much due to deviation from the gas law but due to an inherent source of error. It is felt that this can be rectified by using a suitable grease such as 'APIEZON' used in vacuum pumps[2].

3. Wind Mill

Introduction

Our attention was drawn to meet out the drought situation in Rajasthan. Several aspects such as (i) to search for sub-soil water and to pump it out, (ii) to conserve the available resources by checking evaporation, and (iii) the use of hydroponic method were taken into consideration. I felt interested in harnessing wind energy for pumping out sub-soil water. The blowing of wind has been used to run a wind mill in several countries including India. The power generated by the wind mill can be converted into electrical energy which can be used to work out the water pump. Thus, growing enough fodder for the animals.

Being a participant of this project, I chose to construct a suitable wind mill. There were several questions : why wind mills are not popular these days especially in Rajasthan ? What can be the most suitable design for wind mill to be used here ? I, therefore, studied the available information and principles of wind mills. Wind mill is an arrangement of sails or blades which will turn the shaft to which they are attached, when exposed to wind. There are four types of wind mills :

(1) Multi bladed turbine wheel or American type
(2) Dutch type
(3) Propeller type—high speed wheel
(4) Rotor type.

Design of the American type wind mill

In the American type of wind mill, the sail surface is usually formed from wooden or metal blades. The sail area is changed by opening or closing the blades, either by hand or by a suitable automatic governor. The blades are much greater in number than the European sails and occupy comparatively, a much larger part of the area swept by them. This makes it possible to reduce the diameter of the wind wheel, for a given power, considerably below that necessary in the European wind mill. The American wind mill is usually mounted on a tall open frame work tower, and may utilize a more simple direction vane. Power is transmitted from wind wheel to the point of power utilization by a reciprocating vertical rod or as in the geared type, by a rotating shaft. The useful power actually developed in the American type wheel is 10 p.c. The starting torque and, therefore, the wind speed at which the wheel will start, is largely determined by the blade angle; the greater its pitch, greater is the starting torque but the running speed is lower.

To allow the wind wheel to be turned as the direction of the wind changes, the upper part of the supporting structure rests on rollers so as to rotate about the vertical axis of the tower, often a building of stone. An auxiliary tail wheel is provided to maintain the main wheel properly oriented with respect to the wind.

Rajasthan wind condition

In Rajasthan, wind blows very fast, especially in desert areas (it is also an important factor in soil erosion). We can find out the wind velocity by anemometer and in the absence of this by an improvised apparatus named wind velocity indicator and to make it possible to use wind power in running wind mill, to pump out the water from the areas where the water level is not more than 200 feet deep.

Theory

The kinetic energy (K. E.) of air moving at a velocity V is given by $\frac{1}{2}MV^2$—(i) where M is mass of air.
For a wheel of diameter D, the wind flowing through its cros-section in one second is KD^2V, where K= constant

$$M = \frac{\pi D^2 V P}{4}$$

P= density of air.

We substitute for M in Eq No. (i) $4\ \text{K.E.} = kD^2V^3$.
Power $P = \text{K.E./sec.} = kD^2V^3$ (where k is a constant).

Only a fraction of this power is developed in the mill wheel depending on the design, e.g. in American type of wind mill, this fraction is 1/10.

Taking mass of 1 cu. ft. air=0.0763 lb., the diameter (D) of the wheel in ft. and the wind velocity (V) in mph.

Theoretical wind power (H.P.)$= 5.36 \times 10^{-6} \times D^2 \times V^3$

Further, the conditions of water level in Rajasthan suggest that the average water level is about 200 to 300 ft. deep.

Calculation for the diameter of the wheel of a wind mill

1. Average depth of the water in the drought effected area=200 to 300 ft.
2. Average wind velocity in the drought effected area=15 to 20 mph.
3. Power of the wind mill required to pump out the water from the depth of 300 ft. through pipe of 2″ diameter with a water velocity of 10 ft. per second is given by :

$$P = \frac{\pi}{4} \times \frac{2}{12} \times \frac{2}{12} \times 10 \times 62.4 \times 300 \text{ lb. wt.}$$

$$= \frac{\pi}{4} \times \frac{2}{12} \times \frac{2}{12} \frac{10 \times 62.4 \times 300}{550} = \frac{52}{7} \text{ H.P.}$$

Since actual power developed in the American type wheel is 10 p.c., the theoretical power of the wind must be ten times more than that of the wind mill.

i.e. Theoretical wind power $52/7 \times 10$ H.P. $=75$ H.P. nearly.

4. To develop theoretical wind power of 75 H.P. with a wind velocity 20 ft./sec., the diameter of the wind mill wheel is given by :

$$75=5.36\times10^{-6}\times D^2\times V^3$$

$$\text{or } D^2=\frac{75\times10^6}{5.36\times20^3}=\frac{75\times10^3}{5.36\times8}$$

$$\text{or } D=\frac{75\times10^3}{5.36\times8}=42 \text{ ft. nearly.}$$

A model of the wind mill can be constructed by reducing the above data suitably as given below :

Depth of the water $=30$ ft.

Diameter of the pipe $=1''$

Velocity of the water through pipe $=1$ ft./sec.

Required power of the wind mill

$$=\frac{3.14\times1\times1}{4\times12\times12}\,62.4\times30\times1/550 \text{ H.P.}$$

$$=\frac{3.14\times1.3}{4.55}=0.1855 \text{ H.P.}$$

Theoretical wind power $=0.1855\times10$ H.P. $=1.855$ H.P.

$=2$ H.P. nearly.

$$\therefore\ 2=5.36\times10^{-6}\times D^2\times V^3$$

$$D^2=\frac{2\times10^6}{5.36\times20^3}$$

$$\text{or } D=\frac{2\times10^2}{5.36\times8}=6.8 \text{ ft. nearly.}$$

To support the wind mill on the ground, a proper size of footing is provided. The footing can be fabricated from steel, giving sufficient area at the base to resist the tilting of the wind mill. On this footing, we can rigidly attach a pedestal so as to mount the wind mill at the required height properly. In our model, this height is 8 ft. On the pedastal, we shall provide suitable bearings for the rotating wheel of the wind mill. The wheel of the wind mill shall rotate in a vertical plane. The wheel shall be fabricated of three steel rings of diameter 7′, 5′ and 3′. These steel rings will have aluminium blade equally spaced all around their peripheries.

The motion of the wheel is transmitted to the lower shaft through chain and sprocket wheel mechanism. From lower shaft, the motion is given to a pump by some suitable mechanism.

Materials required

1. Pedestal—1¼″ G.I. Pipe of 8″ length.
2. Iron rods (steel)—¼″ of 30″ length.
3. Aluminium sheets—20 sq. ft.
4. Sprocket and chain—one set.
5. Pump—Rotary or Reciprocating.
6. Pipe—¼″ or 3/8″ of 45 ft. length.
7. Screws, nut bolts, etc.

Working

When wind blows with a certain velocity, the wind power is developed in it. 10 p.c. of this wind power is actually developed in the wind mill which puts its wheel into motion. As the wheel rotates, the power is produced. This power is transmitted to the lower shaft through chain and sprocket wheel mechanism. From there it is given to the pump by suitable mechanism and the pump begins to work.

Conclusion

In Rajasthan, where the depth of water is below 200 ft., wind mill can be successfully used to work on the water pump. Actual construction of the model could not be taken up because of shortage of funds and time.

Further questions

1. What determines the power ratio in the wind mill ?
2. What design of blades, blade angles, and number of blades should be chosen ?
3. How should the trapped energy be stored for the period when wind does not blow ?
4. What should be an alternative to the pump ?
5. Can the indigenous system used in village (RAHAT) be utilised[8]?

4. How to Find out the Thickness of the Penetration of Ink on a Writing Paper

Why this problem ?

One day, I was writing an essay in my note-book. Suddenly, my pen leaked and a drop of ink fell on the paper. I brought a piece of blotting-paper and applied it to the drop. Immediately, the blotting-paper soaked the ink, which came on the other side of it. Thus, the ink penetrated the whole of the width of the paper. At that time, it struck me that it would be interesting if I could measure the thickness to which ink penetrates on an ordinary writing paper, while writing on it. I thought over to solve this problem.

Hypothesis ; and help sought

First it was thought that it might be possible to measure the penetration of ink with the help of a screw gauge. The thickness of the paper was found out with the help of a screw gauge and it was about ·00725 cm. Then letters were written on the paper and carefully erased with the help of a blade. Then the thickness of the paper was again found out at the place where the letters had been erased. It was observed that the thickness was of the order of 10^{-3} cm. It also showed a great variation from point to point. I talked about this problem to my science teacher. He pointed out that the paper was not uniformly porous and to find the average thickness of the penetration of the ink, a large number of observations would have to be made. To avoid this, he asked me to try some other method which might give more accurate and average results.

To apply this idea, it was thought that whole of the surface of the paper should be utilized in this experiment. So a brush was used instead of pen and whole of the paper was smeared with ink uniformly. To avoid taking a large number of observations, the following method developed into my mind.

First the weight of the paper may be found out. Then the dimensions of the paper may be found out. Then density of the paper may be calculated by dividing mass by the volume and the paper may be uniformly smeared with ink with the help of a brush. When it dries, the ink may be erased with the help of a blade.

Then the paper may be again weighed. The difference would give the weight of the paper erased. By dividing this weight by density of the paper already found out, we get volume of the paper erased. By dividing the volume of the paper erased by the area of the paper, we get the thickness of the paper erased. This is surely the average thickness to which the ink penetrated.

Suggested procedure

According to the suggestion of the teacher, first this method was tried out on a thick card-board ; then on a thick paper ; and then finally on an ordinary unruled writing paper.

Presentation of data, calculation and result

The observations, calculations and results are now given below :

For Card-Board

Weight of the card-board =98.055 gms.
Length of the card-board =37 cm.
Breadth of the card-board =11.6 cm.
Least count of the screw-gauge =0.0005 cm.

Observations for the thickness of card-board :

S. no.	*Main scale reading (cm)*	*Circular scale reading (cm)*	*Total thickness (cm)*	*Average thickness (cm)*
1	0.3	11×.0005= .0055	0.3055	0.3135
2	0.3	26×.0005= .0130	0.3130	
3	0.3	43×.0005= .0215	0.3215	
4	0.3	35×.0005= .175	0.3175	
5	0.3	20×.0005= .0100	0.3100	

Hence the thickness of the card-board =0.3135 cm.
Area of the card-board =37×11.6
=429.28 sq. cm.
Volume of the card-board =37×11.6×0.3135
=134.7423 cc.

$$\therefore \text{Density of the card-board} = \frac{\text{Mass of the card-board}}{\text{Volume of the card-board}}$$

$$= \frac{98.005}{134.7423}$$

$$= 0.727 \text{ gm./cc.}$$

Weight of the card-board after erasing the ink
$= 90.720$ gm.

Weight of the erased card-board $= 98.05 - 90.720 =$ 7.335 gms.

Volume of the erased card-board

$$= \frac{\text{Mass of the erased card-board}}{\text{Density of the card-board}}$$

$$= \frac{7.335}{0.727} = 10.089 \text{ cc.}$$

Thickness of the erased card-board

$$= \frac{\text{Volume of erased card-board}}{\text{Area of the card-board}}$$

$$= \frac{10.089}{429.08} = 0.0234 \text{ cm.}$$

Hence the thickness of the erased card-board $= 0.0234$ cm.

For thick Paper

Weight of the thick paper	=25.525 gms.
Length of the thick paper	=55.9 cm.
Breadth of the thick paper	=23 cm.
Least count of the screw-gauge	=0.0005 cm.

Observations for the thickness of the thick paper :—

S. no.	*Main scale reading (cm.)*	*Circular scale reading (cm)*	*Total thickness (cm)*	*Average thickness (cm)*
1	0	53×.0005=.0265	0.0265	0.0232
2	0	50×.0005=.0250	0.0250	
3	0	38×.0005=.0190	0.0190	
4	0	48×.0005=.0240	0.0240	
5	0	51×.0005=.0225	0.0225	
6	0	45×.0005= 0205	0.0205	
7	0	39×.0005=.0195	0.0195	
8	0	52×.0005=.0260	0.0260	

Hence, the thickness of the thick paper
$=0.0232$ cm.

Area of the thick paper $=55.9\times23$
$=1285.7$ sq. cm.

Volume of the thick paper $=55.9\times23\times20.0232$
$=29.8284$ cc.

$\therefore$ Density of the thick paper

$$=\frac{\text{Mass of thick paper}}{\text{Volume of thick paper}}$$

$$=\frac{25.525}{29.8284}$$

$=.856$ gm./cc.

Weight of the thick paper after erasing the ink
$=19.278$ gms.

Weight of the erased thick paper $=25.525-19.278$
$=7.247$ gms.

Volume of the erased thick paper

$$=\frac{\text{Mass of the erased thick paper}}{\text{Density of the thick paper}}$$

$$=\frac{7.247}{.856}=8.466 \text{ cc.}$$

Thickness of the erased thick paper

$$=\frac{\text{Volume of the erased thick paper}}{\text{Area of the thick paper}}$$

$$=\frac{8.466}{1285.7}=0.0068 \text{ cm.}$$

Hence, the thickness of the erased paper $=0.0068$ cm.

For Ordinary Writing Paper

Weight of the paper $=3.787$ gms.

Length of the paper $=33$ cm.

Breadth of the paper $=20.5$ cm.

Least count of screw gauge $=0.0005$ cm, Observations for the thickness of the paper are given below :-

S. no.	*Main scale reading (cm)*	*Circular scale reading (cm)*	*Total thickness (cm)*	*Average thickness (cm)*
1	0	15×.0005=.0075	0.0075	
2	0	16×.0005=.0080	0.0080	
3	0	14×.0005=.0070	0.0070	0.00725
4	0	13×.0005=.0065	0.0065	

Hence, the thickness of the paper =0.00725 cm.
Area of the paper=33×20.5 =676.5 cm.
Volume of the paper=33×20.5×.00725=4.906625 cc.

$$\therefore \text{Density of the paper} = \frac{\text{Mass of the paper}}{\text{Volume of the paper}}$$

$$= \frac{3.787}{4.906625} = 0.77 \text{ gm./cc.}$$

Weight of the paper after erasing the ink=3.005 gm.
Weight of the erased paper=3.787—3.005=0.782 gm.
Volume of the erased paper

$$= \frac{\text{Mass of the erased paper}}{\text{Density of the paper}}$$

$$= \frac{0.782}{0.77} = 1.015 \text{ cc.}$$

∴ Thickness of the erased paper

$$= \frac{\text{Volume of the erased paper}}{\text{Area of the erased paper}}$$

$$= \frac{1.015}{676.25}$$

$$= 0.0015 \text{ cm.}$$

Hence, the thickness of the erased, ordinary writing waper=0.0015 cm.
Hence, the ink penetrates to the depth of 0.0015 cm. in the ordinary writing paper.

Conclusion

The same ink penetrates more into the thick paper and less in thin papers. Secondly, I noted that the depth of the paper to which ink reaches is greater in case of rough papers and lesser in case of art papers[4].

Section B

CHEMISTRY

5. Determination of Molecular Weight of Volatile Liquids

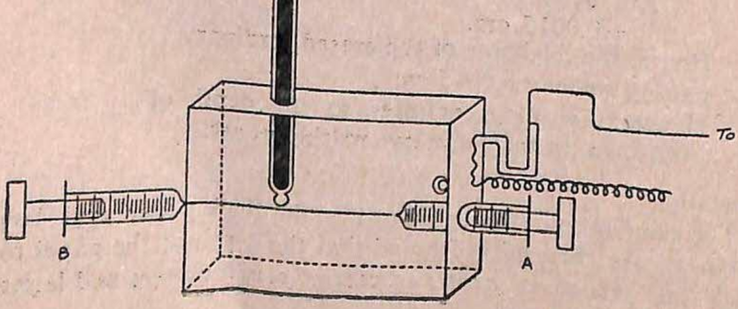
The starting point

Molecular weight of volatile liquids is determined by Victor Meyer's, Duma's, or Hoffmann's method. These methods are cumbersome as well as the cost of the equipment is quite high. A much easier method has been suggested by Badman (The School Science Review, The Journal of the Association for Science Education—1968, Vol. 49,904). Certain modifications have been made in the suggested equipment.

Materials used

Syringe — 100 ml — one
Syringe — 5 ml — one

Wood from packing case, electric bulb (100 watts), 25 cm glass tube (6—8 mm diameter), mercury 2 ml., a glass plate of 25 cm × 25 cm and thermometer.



Method

Fit the syringe A (100 ml) and B (5 ml), as shown in the diagram, in the wooden box of size 25 cm × 25 cm × 25 cm made from wood. One side of the box should have glass. In order to make the box better insulated, lining of asbestos pad can be given. Fix the bulb C, connecting it to the mains through the U-tube made from the glass tubing containing mercury. This arrangement works very well for controlling the temperature within 0.5 °C. Fix thermometer as shown in the diagram

Procedure

Connect the bulb to the mains and wait till the temperature of the box is 100 °C. Fill the syringe B with the experimental volatile liquid. Inject the liquid in syringe A, wait till the volume of the vapour in syringe A is about 50 to 60 ml. Note the volume of the liquid pushed in from syringe B. Note the atmospheric pressure. From the density of the liquid, find out the weight of the liquid pushed in. Calculate the molecular weight by applying gas equation.

Another method of finding out the molecular weight is to have two volatile liquids. The molecular weight of one of the liquids should be known. Inject the liquid whose molecular weight is known in the large syringe so that the volume of the vapour is 50 ml. Find out the weight of the liquid injected. Empty the syringe A. The other liquid whose molecular weight is to be determined is pushed in syringe A till the volume of the vapour is again 50 ml. Find out the weight of the liquid injected. Molecular weight is calculated from the formula :

$$\frac{\text{wt. of 50 ml of liquid vapour of known mol. wt.}}{\text{wt. of 50 ml of liquid vapour of unknown mol. wt.}} = \frac{\text{mol. wt. of known liquid}}{\text{mol. wt. of unknown liquid}}$$

Molecular weights of chloroform and acetone were determined with this apparatus within ± 2%. The cost of the equipment was about Rs. 30/-.

Further problems

Can we use this equipment for verifying Charle's law? Think of some other utility of this equipment [5].

6. Paper Chromatographic Separation of Copper and Iron

Introduction

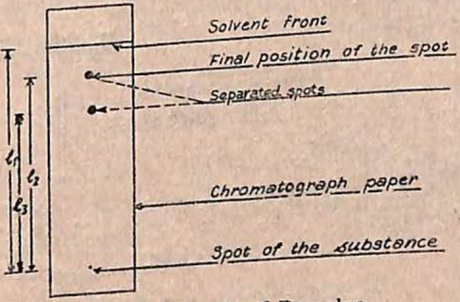
Chromatography is a modern technique of beautiful simplicity. It is a far more subtle method of separation than the traditional chemical techniques of distillation, precipitation with reagents and crystallisation. According to Beaver, "The field is so new that it is open to all comers. The amateur has a good chance of making a worthwhile contribution to the technique." We, students of the Pre-degree Course in Kerala, have to study very little on chromatography. We have to study what is meant by the terms "Adsorbent", "Chromatography", "Elution", "Eluent" and how a mixture of copper and nickel salt solutions can be separated on a column of alumina. Like many other students, I was also fascinated by this very interesting technique which is similar to the formation of a spectrum on passing white light through a prism. One day I came across an article in a journal in which the author had given an ingenious, simple method of separating mixtures of metallic salts in solution on chromatographic paper (descending type) using a cheap home-made apparatus consisting of a large test tube, a glass tube, few paper clips and some glass pieces. It was the simplicity of the experiment that inspired me to select this project.

Selection of the problem

Here an endeavour is made to study the effect of the concentration of the solvent on the R_f value of the substance dissolved in the solvent and the efficiency of separation of a mixture of two substances in solution. The separation of iron and copper was selected. The phase on which the substances separate was paper. The particular reason for choosing paper chromatography is its simplicity.

Theoretical background

The R_f value of a substance for a particular solvent measures the rate at which the dissolved substance advances with respect to the solvent, when the solution spreads upon the material. Thus, if the solvent advances through a distance L_1 units, while the dissolved substances moves through a distance L_2 units at the same time (both distances being measured from the point where a spot of the substance is applied, then the R_f value of the substance for the solvent is given by $\frac{L_2}{L_1}$, that is, $R_f = \frac{L_2}{L_1}$



Definition sketch of R_f value.

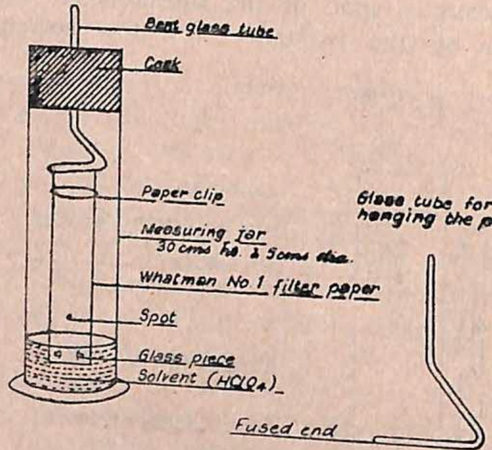
If the spot applied is a mixture of the solutions of two metal salts, say, those of iron and copper, then the ratio of their R_f values in a particular concentration of the solvent is a measure of the efficiency of separation. Greater the variation of the ratio of the R_f values of the substances from unity in a particular concentration of the solvent, greater will be the separation.

Experimental work

The experimental work consisted in determining the R_f values of iron and copper perchlorates in various concentrations of the solvent, perchloric acid. The ascending type of paper chromatography was used.

Design of apparatus

The apparatus used was simple. It consisted of a measuring jar (5 cms in diameter and 30 cms long) closed with a nonholed cork carrying a tube bent as shown in the figure below, in order to facilitate the suspension of the chromatograph paper on it. Near the other end of the paper, a small glass piece was suspended horizontally, so as to hang the paper vertically. The length of the paper was adjusted so that its end and the glass piece was completely under the solvent (perchloric acid) taken in the jar.


Bent glass tube
Cork
Paper clip
Glass tube for hanging the paper
Measuring jar 30 cms ht. & 5cms dia.
Whatman No 1 filter paper
Spot
Glass piece
Solvent ($HClO_4$)
Fused end

Experimental set up (not to scale).

Papers varying in widths from 2-3 cms were used for the different experiments. Three jars of about the same length and diameter were used together, so that three experiments could be performed at a time.

Materials used

(1) Perchloric acid. 60% perchloric acid (Riedel) was available in the laboratory. Using this, different concentrations of perchloric acid were prepared by diluting it with the required volume of distilled water and standardising against sodium carbonate (guaranted reagent-S. Merck).

(2) Neutral solution of ferric perchlorate. Ferric oxide was treated with perchloric acid to see whether it dissolves. There was no change. This seems to be due to aging. So first prepared ferric hydroxide by treating ferric chloride solution with excess of ammonium hydroxide. The precipitated ferric hydroxide was filtered, washed with distilled water

until free from ammonia and then treated with perchloric acid to obtain a neutral solution of ferric percholorate, that is, till no more of the ferric hydroxide dissolved. The undissolved ferric hydroxide was removed by filtration.

(3) Neutral solution of cupric perchlorate. As a first step, cupric oxide was prepared by heating the pale blue precipitate of cupric hydroxide obtained by adding excess of sodium hydroxide to copper sulphate solution. The black precipitate of cupric oxide was washed free from alkali, filtered and treated with perchloric acid to obtain a neutral solution of cupric perchlorate.

(4) Developing reagent. Potassium ferrocyanide. A 2% solution of potassium ferrocyanide was used as the developing reagent as it gives a blue colour with ferric salts and a chocolate brown colour with copper salts.

(5) Chromatographic paper. Whatman No. 1 filter paper was used.

(6) Perchlorates and perchloric acid. Perchloric acid and perchlorates were selected for the work, since they are maximally ionised in solution.

Procedure

Cut out a strip of whatman No. 1 filter paper (about 27 cms long and 3 cms wide). Suspended this from the glass tube introduced into the one-holed cork, and kept it in position with the help of a paper clip. Near the other end of the paper, two small holes were made in order to introduce a small glass piece horizontally through it. This glass piece served to keep the paper vertical. A small dot was made with a pencil on the paper ; about 3 cms from the bottom end. With the help of a micro-pipette, a spot of the ferric perchlorate solution was made on the pencil dot. Allowed the spot to dry. About 25 cc of 0.83N perchloric acid was taken in the measuring jar, which was previously washed and cleaned. Now inserted the cork with other attachments into the mouth of the jar. Care was taken to see that the paper was exactly vertical and that the spot was well above the level of the solvent in the jar. Waited till the solvent had advanced to a good, reasonable height. Took out the paper and immediately marked the solvent front with a pencil. The paper was allowed to dry in sunlight. When the paper was perfectly dry, it was sprayed with potassium ferrocyanide solution with the help of a spraying gun. A blue colour was developed at the contact place of iron and potassium ferrocyanide. The position of the blue colour was marked and distances L_1 and L_2 (refer diagram on page 195) were measured and R_f value was calculated. $R_f = \frac{L_2}{L_1}$, where L_2 and L_1 are the distances advanced by the substance and the solvent respectively. The experiment was repeated using perchloric acid of varying strengths and in each case the R_f value was determined. Performed the same experimental procedure in the case of copper perchlorate also. In the case of copper, the colour produced by potassium ferrocyanide is chocolate brown. The readings were tabulated.

Observations

No.	Acid strength	Distance moved by spot (L_2) cms	Distance moved by the solvent (L_1) cms	$R_f = \frac{L_2}{L_1}$	Average R_f
		For Ferric Perchlorate			
1	0.83 N	8.2 8.2	10.5 10.4	0.7809 0.7884	0.78465
2	0.498 N	8.5	11.5	0.7391	0.7391
3	0.415 N	8.3 7.7	11.2 10.5	0.7411 0.7333	0.7372
4	0.2075 N	6.4	10.3	0.6214	0.6214
5	0.083 N	3.7 3.7	10.2 10.5	0.3627 0.3522	0.35745
		For Cupric Perchlorate			
1	0.7 N	10.3	11.9	0.866	0.866
2	0.42 N	10.0	12.0	0.833	0.833
3	0.35 N	9.15	10.75	0.836	0.836
4	0.175 N	7.9	10.2	0.775	0.775
5	0.07 N	6.1 6.3	11.5 12.4	0.530 0.509	0.519

Difficulties involved in the experiment

1. In the case of iron, it was noted that as the solvent ascended the paper, it bent into a V-shape form on coming into contact with the spot, and then after sometime, the solvent front became almost straight.

2. In the case of iron, diffused V-shaped zones were obtained in all the experiments on development of the blue colour with potassium ferrocyanide. So took the base of the 'V' as the final position occupied by iron for calculating R_f values.

3. In the case of copper, there was a certain greenish-blue colour development on the paper where the solvent had touched. This may be due to the presence of impurity: iron.

4. The chocolate brown one formed in the case of copper was oval-shaped. Took the centre of this oval-shaped zone as the final position of copper for calculating its R_f values.

Treatment of experimental data and interpretation

A graph was drawn taking concentrations of the solvent along the x-axis and R_f values along the y-axis, to see the variation of R_f value with concentration. It is seen that the variation is high up to acid concentration 0.25N in each case. The shape of the graph shows that if the R_f values are plotted against log concentration of the acid, a straight line graph must result. The graph was drawn and it was a straight line.

It showed that irrespective of the acid concentration, the difference in the R_f values of iron and copper remains more or less the same. Hence, the efficiency of separation is independent of the concentration of the acid employed. This is true only above a certain concentration of the acid, since below this concentration, the zone formed spreads all over the paper without any definite shape. It is preferable to use acid concentrations above 0.2N as the solvent, since there is a definite shape for the band and spreading is minimum.

Summary

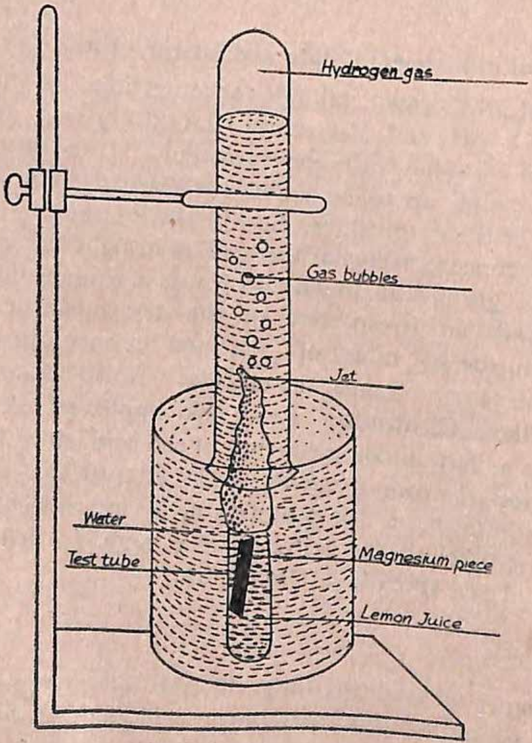
The paper chromatography of iron and copper perchlorates were performed using perchloric acid as the solvent. It is found that the R_f value increases, in both cases, with increase in concentration of the acid[6].

7. Acidity of Lemon Juice

Since long, we have been using lemons and oranges as a part of our meals. Common experience is that they are sour in taste. In my chemistry class, I learnt that acids are also sour in taste and they react with metal to give hydrogen. I thought if all mineral acids give hydrogen when reacted with metals, lemon or orange juice must also give hydrogen if allowed to react with metal. The qualitative generalization made an interesting opening for the search of a quantitative relationship.

Statement of the problem

To find out the amount of acidity in one ml of lemon juice in terms of volume of hydrogen generated.



Materials required

Lemons, few small test tubes 4″ × 1″, beaker 500 ml, graduated tube closed at one end or burette, rubber bands or strips, magnesium ribbon of good quality, spirit lamp, glass tube with fine jet at one end and filter paper.

Method

1. First of all, magnesium ribbon was placed in lemon juice to see whether or not lemon juice reacts with magnesium. In this case, reaction started after 1-2 minutes and it was very slow.
2. Collected one ml fresh lemon juice in a small semi-micro test tube and added water to fill it to the top of test tube. Placed one inch piece of magnesium ribbon into the solution and attached a fine jet to the flask. Immediately inverted a graduated tube (eudiometer tube) over the jet and held the tube in upright position as shown in the diagram. Collected the evolved hydrogen gas. Repeated these with one ml juice from fresh lemons and lemons kept for different periods (after one day, two days).

Precautions

1. No air should enter the graduated tube.
2. Hydrogen bubbles should not escape from the graduated tube.
3. Before the first bubble from small test tube escapes, graduated tube should be inverted.
4. When no more bubbles come out, juice should be tested with methyl orange.
5. Magnesium ribbon should completely dip inside the diluted solution of juice.

Observations

S. No.	*Approximate age*	*Quantity of juice (ml)*	*Volume of H_2 produced (ml)*
1	Fresh	1.0	16.2
2	Less fresh	1.0	15.8
3	Still less fresh	1.0	15.6
4	Old	1.0	15.1
5	Older lemon	1.0	15.0
6	Still more older	1.0	14.8
7	Oldest lemon	1.0	14.2

Generalizations

1. Fresh lemon gave maximum hydrogen.
2. Oldest (i.e. 4 days old) gave the minimum.
3. Volume of hydrogen went on decreasing as lemon grew older.

Problems not clear

1. Reasons for the above findings.
2. Whether only one type of acid is present or more than one are present.
3. Why the acidity of lemon decreased with increasing length of time.

Further problems

1. Instead of taking observations from one lemon of each type, a better procedure would be to try 6-7 lemons of same age, then find mean acidity of all.
2. Check the validity of same generalization from other fruit juices.
3. Check the results from titration data also using indophenol blue as an indicator.

Difficulties encountered

1. It was difficult in the beginning to set up apparatus for collection of hydrogen. The apparatus mentioned above solved this problem.
2. Could not use pure juice but used juice as a whole containing fibrous parts[7].

Section C

BIOLOGY

8. Microorganisms Present in Gut of Frog

Introduction

This is uniqueness of nature that many organisms live inside other organisms and adapt themselves completely to that environment and in that they perform all the activities of a living being. I had read about many of such organisms but I had never seen one. So I was curious to get a glimpse of such organisms.

Selection of the project

Almost all of the larger animals must be lodging these smaller organisms inside their systems. I selected the frog to study. As frog is an animal which is easily available and it is studied at school all over India. This animal is handy also. So I thought it would be better if I search in frog for these organisms. As it is easier to look for these microorganisms in gut so I thought I would search for these organisms there.

Statement of the problem

To find out types of microorganisms present in gut of frog.

Hypotheses

(i) Many microorganisms are likely to be present in gut of frog.
(ii) Most of them will be protozoans.
(iii) Majority of them will be found in rectum.

Materials needed

Microscopes, slides, stain, dissecting dish, dissection box, petri dishes, graduated jar, balance.

Procedure

Saline solution of 0.7% concentration was prepared by adding 3.5 gms of sodium chloride in 500 cc of water. Five fresh frogs were made unconscious with the help of chloroform. Their alimentary canals, were exposed and brought out one by one. Each alimentary canal was divided into 3 pieces. (i) Oesophagus + Stomach, (ii) Intestine, (iii) Rectum. Now there were 5 pieces of Oesophagus and Stomach, 5 pieces of Intestine and 5 pieces of Rectum. Each piece was put in a petri dish and small amount of saline water was added to each dish. The quantity of saline water was such that each part was completely immersed in saline solution in their respective petri dishes. Saline solution was used here as it provides the organisms same environment which is present in alimentary canal. Petri dishes were labelled.

Each part was given a longitudinal cut with the help of scissors. With the help of tongue needle, the contents present in different parts were thoroughly mixed into the saline solution in their respective dishes. Now each part was picked up and thrown away. The contents of stomach, intestine and rectum of frog A were observed under microscope, for microorganisms, one by one. This study was done by making 12 temporary slides, one by one, of the (i) contents of Oesophagus and Stomach, (ii) contents of Intestine, (iii) contents of Rectum. Rest of the specimens could not be studied that day due to shortage of time. Contents from each of the petri dishes was transferred to test tubes. Saline solution was decanted from each test tube. Required amount of 70% alcohol was added. Next day alcohol was decanted from each test tube, water added and solutions were again transferred to respective petri dishes. Slides were prepared from each sample and stained with methylene blue and observed under microscope.

Observations

Microorganisms were found in all the 3 parts of alimentary canal. They were easily identified under living condition due to their movement. The fixed specimen could only be identified with the help of observations already done about living specimens.

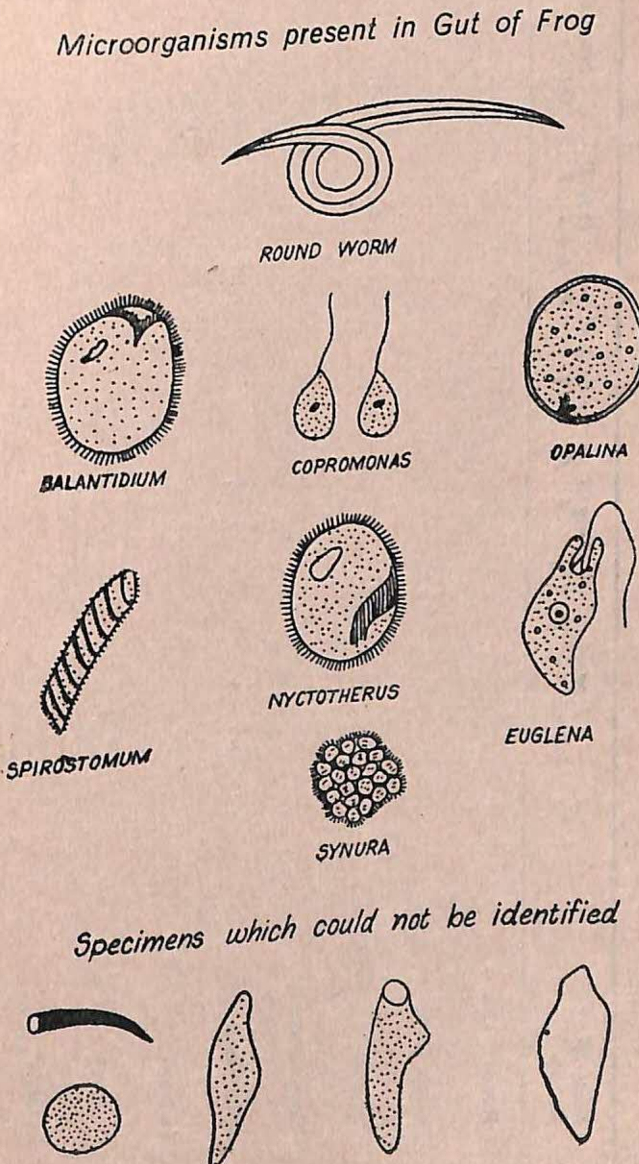
All the microorganisms could not be identified.

Interpretation of data

The common microorganisms found in the gut of frog are : Round worm, Nyctotherus, Opalina, Copromonas, Balantidium, Euglena, Synura, Spirostomum and Trematod.

Conclusions

1. Many microorganisms were present in gut of frog.
2. Most of them were protozoans.
3. Majority of them were found in rectum.


Microorganisms present in Gut of Frog
ROUND WORM
BALANTIDIUM
COPROMONAS
OPALINA
SPIROSTOMUM
NYCTOTHERUS
EUGLENA
SYNURA
Specimens which could not be identified

Microorganisms present in gut of frog.

Tabulation data :

A.

S. No.	*Name of parasite*	*Frog A* *O+S*	*I*	*R*	*Frog B* *O+S*	*I*	*R*	*Frog C* *O+S*	*I*	*R*	*Frog D* *O+S*	*I*	*R*	*Frog E* *O+S*	*I*	*R*
1	Round worm			+	+	+			+	+	+	+	+			
2	Balantidium			+			+						+			+
3	Opalina			+		+	+				+	+	+	+	+	+
4	Copromonas			+			+						+		+	+
5	Nyctotherus	+	+			+	+				+		+	+	+	+
6	Euglena	+		+												
7	Synura	+		+												
8	Trematod										+					
9	Spirostomum		+									+				

B.

S. No.	*Parasites*	*Oerophagur +Stomach*	*Intestine*	*Rectum*
1	Round worm	Frog B Frog D	Frog B Frog C Frog D	Frog A Frog C Frog D
2	Balantidium	X	X	Frog A Frog B Frog D Frog E
3	Opalina	Frog D Frog E	Frog B Frog D Frog E	Frog A Frog B Frog D Frog E
4	Copromonas	X	Frog E	Frog A Frog B Frog D Frog E
5	Nyctothesus	Frog A Frog D Frog E	Frog A Frog B Frog D	Frog B Frog D Frog E
6	Euglena	Frog A	X	Frog A Frog E
7	Synura	Frog A Frog B	X	X
8	Trematod	Frog D	X	X
9	Spirostomum	X	Frog A Frog D	X

Limitations

1. All microorganisms could not be identified.
2. It would have been better if living specimens could have been observed.
3. Permanent slides of parasites could not be prepared.
4. Vital stain could not be given to microorganisms.

Further investigation

Life cycle and behaviour study of different microorganisms can be done by providing same environment as inside the guts[8].

9. Effect of Some Acids on Germination and Growth of Some Seeds

Exact Title : The Effect of Gibberellic Acid and Phosphon on Germination of Pea and Bengal gram seed; and on Growth of Pea Seedlings and Bengal gram Seedlings.

Introduction

In addition to water, light, carbon dioxide and various other materials absorbed by a plant from its environment, other chemicals are required for plant growth. These substances are called hormones. By appropriate experimental technique, we can deplete their supply in the plant, demonstrate their existence and deduce a great deal about their nature. In the 1930's, Japanese physiologists and chemists isolated from the fungus gibberella, several growth medium substances, some inhibitors and some growth promoters. In 1955, British scientists isolated a substance named gibberellic acid which when applied to plants produced tremendous hyperelongation effects on stems. The above facts aroused our curiosity in understanding more about growth regulators. Hence we selected this project.

Aim

Our aim was to find out the effects of :

1. Gibberellic acid on germination of pea seeds and growth of the seedlings.
2. Gibberellic acid on germination and growth of gram seed.

3. Phosphon on germination and growth of pea seed.
4. Phosphon on germination and growth of gram seed.

Soaking: 24-4-69

Fifty seeds each of pea and bengal gram were soaked in solutions of 0.5501% of gibberellic acid and 0.5501% phosphon in four containers. 150 seeds each of both the seeds were taken and soaked in water in another two containers.

We examined the seeds after 24 hours. The observations made are summarised in the following tables.

Table 1. 24 Hours after Soaking

Pea seed *control group*	*Gram seed* *control group*
Seeds got swelled up by absorption of water. Testa of about 10% have bursted	Seeds got swelled up. Testa of almost all have been bursted. About 50% have germinated. In some the radicle was 2 cm long and in some others 1 cm
Soaked in gibberellic acid	Soaked in gibberellic acid
The testa of about 40% have bursted. The radicle has not elongated	Only a single one (2%) has germinated when all have swelled up
Soaked in phosphone	Soaked in phosphone
The seeds have swelled up but testa of none of the seeds have bursted	The seeds have swelled up but testa of one (2%) of the seeds have bursted

Planting : 25-4-69 11.30 a.m.

The pots were arranged as follows :

Table II. Pea and Gram Seed

	Pea	*Gram seed*
1 Control growth	a	a_1
2 Soaked in gibberellic acid	b	b_1
3 Soaked in phosphon	c	c_1
4 For application of gibberellic acid	d	d_1
5 For application of phosphon	e	e_1

We observed the pots daily and noted the differences in development.

Ten pots were selected and filled with a mixture of soil and sawdust. The seedlings were planted 25 in each pot and watered regularly.

1. The seeds soaked in gibberellic acid showed greater elongation of shoot in the beginning.
2. The seeds soaked in phosphon showed no sign of germination throughout the period of project work.
3. The gram seeds soaked in gibberellic acid did not show any marked difference in growth when compared to control growth in the beginning.

The length of the shoots in the pots was measured daily and noted in the tabular column, II. The graphical representation of growth is also made. There was greater elongation in shoots in the pea plant soaked with gibberellic acid than the control group. But in gram seeds, there was no notable difference. We examined the root system of pea and gram seed in order to see the effect of gibberellic acid on it after five days. The root system of gram seeds of control group showed short tap root with numerous branches. But the gram seed soaked in gibberellic acid had much elongated tap root with no branches.

Some of the seedlings were preserved in 10 p.c. formalin. The respective lengths of roots for gram seed soaked in water and gibberellic acid were found to be 7.6 cm and 13.5 cm.

Application :1-5-69

The solutions were prepared in 0.5501% gibberellic acid and 0.5501% phosphon.

We applied the solution with a smooth brush to the shoot system by gentle rubbing. The effect of gibberellic acid on the shoot of gram seed was greater than that of pea seed (see table). In gram seed and pea seed, the tallest were the seeds soaked in gibberellic acid and shortest in the controls. When phosphon was applied, the plants did not grow and within two days all died. We transplanted some pea plants and gram plants from the control group for application of phosphon.

Application of acids : 2nd stage 7-5-1969

We applied gibberellic acid 1.19% and phosphon 0.2201%. Difference in growth was measured and noted in the table. The higher concentration had tremendous effect in the elongation of shoot. After 17 days, the rate of growth in the pea and gram seed soaked in gibberellic acid showed retardation of speed in growth (see table).

Inference

Gibberellic acid when applied to pea produced hyper elongation effects on stems. It also resulted in diminution of leaf area. We noted that the application of gibberellic acid to the dwarf pea caused the dwarf to assume the tall appearance. It is remarkable to note that the peas soaked in gibberellic acid showed much elongation of stem than the seedling in which the gibberellic acid was applied in stems and leaves. In gram seed, gibberellic acid has no notable effect on stem whereas it has great influence in the elongation of root which has already been mentioned.

The application of phosphon on gram seedlings has adverse effects on stem. Most of them died the next day. When phosphon was applied on lesser concentration (0.2201%), the pea and gram seedlings showed retardation of growth yet they did not die. A few auxillary buds began to sprout.

Conclusion

From the projects we have undertaken it was clear that gibberellic acid and phosphon can stimulate or inhibit growth in different plant species.

Project : Effect of Gibberellic Acid and Phosphon on Growth of Pea and Bengal Gram

	PEA		SEED			BENGAL GRAM			SEED	
Date	*Control* (*cm*)	*Soaked in G. acid* (*cm*)	*Soaked in Phosphon*	*Application of G. acid* (*cm*)	*Application of Phosphon* (*cm*)	*Control* (*cm*)	*Soaked in G. acid* (*cm*)	*Soaked in Phosphon*	*Application of G. acid* (*cm*)	*Application of Phosphon* (*cm*)
25-4-69 11.30 am	2	2.5	—	—	—	3	3	—	—	—
26-4-69	4	6	—		—	4.7	4.5	—	—	—
27-4-69	6	9	—	—	—	5.8	5	—	—	—
28-4-69	6.8	13.5	—	—	—	6.6	5.6	—	—	—
29-4-69	7.6	16	—	—	—	7.4	6.3	—	—	—
30-4-69	8	16.5	—	—	—	9	8.8	—	—	—
1-5-69	9	16.6	—	9	9	10	10.5	—	10	10
,,	—	—	—	Applied the acids .55%	.55%	—	—	—	Applied the acids .55%	.55%

2-5-69	10	17.2	—	10.5	9	12	13	—	12	10
3-5-69	10.8	17.5	—	11	9	13	14	—	13.5	10
4-5-69	11.5	17.8	—	11.5	Died	14	15	—	14.5	10
5-5-69	12	18.1	—	12	Died	14.5	17	—	16.5	Died
6-5-69	12.5	18.5	—	12.5	Replanted from control group	15	20	—	18.5	Replanted from control group
7-5-69	12.8	19.7	—	13	12.8	15.2	23	—	20	15.2
,,	,,	,,		Applied the 1.19%	acids .22%	—	—	—	Applied the 1.19%	acids .22%
8-5-69	13	19.8	—	13.5	12.8	15.5	23.5	—	20.2	15.5
9-5-69	13.2	19.8	—	14.8	12.8	15.7	23.6	—	20.8	15.2
10-5-69	13.8	19.9	—	15.5	12.8	15.9	23.6	—	21.4	15.2
11-5-69	14.1	19.9	—	16	12.8	16.1	23.7	—	22.2	15.2
12-5-69	14.5	20	—	16.5	12.8	16.3	23.7	—	23	15.2
13-5-69	15	20	—	17	12.8	16.5	23.7	—	23.5	15.2

Acknowledgements

In this connection we have great pleasure to thank Mr. Richard Boyagian, U.S. Consultant and Dr. O. M. Mathen, Director of the Summer Institute, for their valuable suggestions and guidance for the proper execution of the project[9].

10. A Study of the Effect of Growth Regulators on Rooting of Bryophyllum Calycinum

Introduction

The root is the descending portion of the axis of the plant. It absorbs water, mineral salts and conducts them to the various parts of the plant. Some plants, besides rooting from the root apex, give out roots from their nodes and internodes, e.g. mint. Others give out roots from their branch cuttings. Some plants also give out roots from the foliar buds developing on leaf margins, e.g. bryophyllum, while in some cases they may also develop from the petiole, e.g. begonia, ficus. In some cases, rooting is very easy as in money plant (pothos) while in other cases it is rather difficult, whether the plant is in water or in soil, as in wild rose. On account of scientific advancement in the biological sciences, some growth promoting substances called hormones have been found which have helped in producing seedless units rooting in cuttings etc. and better crops for marketing. Rooting in hardy species fascinated me very much. If fruit trees like strawberry and ornamental plants like hibiscus and wild rose can be made to root by artificial means, this would greatly help in production of new varieties with great vigour and other advantages of yield to the growers. I wanted to see practically the effects of hormones on rooting of plants which did not root easily as stated above, but due to the paucity of time for completing this project, I thought of studying their effects on bryophyllum and ficus leaves. In this short duration, ficus, however, failed to give roots.

Materials and methods

For experimental convenience, bryophyllum and ficus leaves were taken, for no other plant in such a short time could produce roots. Healthy natural leaves of uniform size were selected. Chemicals such as indole propionic, uric, phenyl acetic acids, uracil and 5-nitro uracil were used. These growth promoting substances accelerate rooting. Stock solution of indole propionic acid was made in 95% alcohol while phenyl acetic, uric acids, uracil and 5-nitro uracil were made in distilled water. Concentrations of 10, 25, 50 mg/1 for indole propionic, uric and phenyl acetic acids while concentrations of 50, 200, 500 mg/1 for uracil and 5-nitro uracil were made. Three leaves were kept in each treatment. Two sets of each concentration were prepared of which one was kept in the light chamber while the other in the dark.

The light chamber had a mixed light of 3 fluoroscent and 4 incandescent lamps. The leaves were soaked into water with the petiole and dripping in it (in the solution for twenty four hours and were then transferred). A control in each set was treated with distilled water. Root and shoot initiation were noted as soon as they were formed, while root number and root length were measured seven days after treatment. The experiment was terminated 12 days after treatment when visible shoots were formed.

The data presented in tables 1 and 2 are simple averages of the total number of length of roots present in all grooves of the 3 leaves in each treatment. Table 3 only shows the presence or absence of shoot formation.

Results

1. Effect of Growth Regulators on Root Formation in Bryophyllum Calycinum

Treatments of indole propionic acid did not have any promotory effect on root formation as compared to the control in any concentration except 25 mg/1 in the dark (Table 1). A concentration of 10 mg/1 of phenyl acetic acid was found to increase the number of roots both in light and dark. Higher concentrations had no promotory effect in light but increased the number in the dark as compared to control.

In treatments of uric acid, the number of roots formed was very poor in light but in a concentration of 50 mg/1 in dark as many as 58 roots per leaf were formed (Table 1). Treatments of uracil did not promote root formation either in light or in dark (Table 1) but treatments of 5-nitro uracil increased the root number in light considerably as maximum root formation occurred in a concentration of 200 mg/1. Generally more roots were formed in all the treatments in dark than in light except in the case of 5-nitro uracil.

Table 1. Effect of Growth Regulators on Root Formation in Bryophyllum Calycinum

	Treatments	*Average no. of roots per leaf*	
		Light	*Dark*
1	Control	15	33
2	Indole propionic acid 10 ppm	7	4
	,, 25 ,,	9	38
	,, 50 ,,	5	27
3	Phenyl acetic acid 10 ppm	16	42
	,, 25 ,,	3	23
	,, 50 ,,	9	33
4	Uracil 10 ppm	16	42
	,, 25 ,,	3	23
	,, 50 ,,	Decayed	33
5	Uracil 50 ppm	9	11
	,, 200 ,,	16	14
	,, 500 ,,	9	29
6	Nitro uracil 50 ppm	23	24
	,, ,, 200 ,,	31	23
	,, ,, 500 ,,	Decayed	16

2. Effect of Growth Regulators on Root Length

Treatment of indole propionic acid increased root length in light as compared to control but in dark the roots were shorter than the control except in a concentration of 25 mg/1(Table 2). In case of treatments of phenyl acetic acid, the reverse was the case, i.e. the roots were longer than the control in the dark than in light (Table 2). In case of uric acid, the root length also increased under control in dark. However, a lower concentration (10 mg/1) also promoted root elongation in light. As in the case of root number, treatments of uracil did not have any significant effect on root length in light. They were, however, found to have some promotory effect in the dark (Table 2). Although treatments of 5-nitro uracil helped in root initiation in light, they did not have as much effect in promoting root elongation either in light or in dark (Table 2). Generally, the roots were longer in dark but; on account of formation of more roots the average length, as shown in table 2, became lower than their counterpart in the light, especially in treatments of indole propionic and uric acids.

Table 2. Effect of Growth Regulators on Root Length of Bryophyllum Calycinum

	Treatments	*Average length of root in mm*	
		Light	*Dark*
1	Control	3.9	2.4
2	Indole propionic acid 10 ppm	6.0	1.9
	,, 25 ,,	5.4	3.2
	,, 50 ,,	4.2	2.3
3	Phenyl acetic acid 10 ppm	3.9	3.6
	,, 25 ,,	1.0	2.9
	,, 50 ,,	1.5	3.9
4	Uric acid 10 ppm	4.2	3.5
	,, 25 ,,	2.9	2.9
	,, 50 ,,	...	4.1
5	Uracil 50 ppm	3.1	3.7
	,, 200 ,,	3.8	3.8
	,, 500 ,,	3.5	3.8
6	Nitro uracil 50 ppm	1.8	2.6
	,, 200 ,,	3.4	2.7
	,, 500 ,,	...	2.1

3. Effect of Growth Regulators in Shoot Formation

Shoots were formed in all the treatments including the control kept in light after a period of 12 days after treatment. However, only in a concentration of 50 mg/l 5-nitro uracil, no shoot formation occurred in light. In most of the cases, two or three green healthy leaves developed and the young seedlings appeared ready for independent growth (Table 3). Development of shoots in dark, on the other hand, occurred only in a few treatments including the control. In cases where shoots were formed, they were weak and cliotated with poorly developed leaves. Light was therefore found essential for normal healthy growth.

Table 3. Effect of Growth Regulators on Shoot Formation in Bryophyllum Calycinum Leaf

	Treatments	*Presence or absence of shoot*	
		Light	*Dark*
1	Control	+	+
2	Indole propionic acid 10 ppm	+	–
	,, 25 ,,	+	–
	,, 50 ,,	+	+
3	Phenyl acetic acid 10 ppm	+	–
	,, 25 ,,	+	+
	,, 50 ,,	+	+
4	Uric acid 10 ppm	+	–
	,, 25 ,,	+	–
	,, 50 ,,	Decayed	–
5	Uracil 50 ppm	+	+
	,, 200 ,,	+	–
	,, 500 ,,	+	–
6	5-nitro uracil 50 ppm	–	+
	,, 200 ,,	+	+
	,, 500 ,,	Decayed	–

Discussion and conclusion

From the experimental results discussed above, it can safely be concluded that treatments of indole propionic, phenyl acetic and uric acids promoted rooting in bryophyllum leaves in dark. Only treatments of 5-nitro uracil had a promotory effect on root formation in light. The root length was also affected more by dark than by chemicals as longer roots were formed in the former. Shoot formation occurred in most of the treatments in light. The chemicals, however, promoted the size of the shoot and the number of leaves. The shoots in all the treatments were formed in light but only a few in dark[10].

Literature consulted

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Acknowledgement

I offer my grateful thanks and compliments to Dr. S. N. Mathur, Department of Botany, Gorakhpur University for giving me facilities to use the botany laboratory and providing me with the requisite chemicals.

Concluding statement

Like a human body, a project has a head, body and feet. It is the individual projecteer's orientation and job to give his project a best possible shape within the broad framework described in the preceding pages. It is so because any project can be investigated from many different aspects. This fact should not be lost sight of while making a final selection of one's own project. Once the mind begins to vibrate, ideas for the project come from different sources namely, personal speculation; speculation on the work of others, newspapers, magazines and project reports, text books and reference books ; conversations with classfellows, friends, parents, relatives and teachers, off hand remarks, talks and conversation with professional people ;

and the frequent encounter of the same problem in diverse situations. Under certain conditions, improvisation or fabrication of equipment itself becomes project for it becomes a vehicle to snatch objective knowledge from nature. For example, most of the world famous scientists fabricated their own equipment for this purpose. The use of sealing wax, candle and string made the Cavendish laboratory world famous. One has to take a risk of buying a pig in the poke not only to satisfy one's curiosity but also to find fun in science. Incidentally as well as intentionally, provided the mind is prepared according to L. Pasteur, one may stumble against original facts or discoveries at a much younger age than hitherto considered. Below are presented a few suggestions in this direction.

(a) Read in general about the phenomenon you are going to investigate. You will thus encounter a few problems and several sub-problems.

(b) Select a problem (may be two tier or three tier) which appeals to you the most ; and also can be investigated in stages. One can then discontinue the project at any desired stage for a limited solution is better than no solution.

(c) Read specifically about the problem under investigation with an open mind. This gives you some vague idea about the way the problem was tackled in the past or is being currently tackled by somebody else.

(d) Now try hard to phrase and rephrase your problem as sharply as you can. If you cannot, it is just the case that you have not really grasped the problem. Try and try again like king Bruce.

(e) Sleep with the problem for sometime in determining the aims of your investigation and the possible ways of tackling it. Select the best strategy suiting your mentality and resources. Prepare a tentative blue print.

(f) Now discuss this blue print with your teacher or a professional scientist, if available nearby.

(g) In the light of the discussions made, improve upon your blue print in regard to aims, hypotheses to be set up, amount of experimentation necessitated, materials and equipment needed, manner of making and recording observations, type of mathematical calculations to be made, likely sources of errors and precautions to be observed. Remember that use of mathematics and statistics strengthens your conclusions which can be further tested. A good project thus tends to be endless in throwing more problems than it solves. It is through the use of one's constructive imagination that the projecteer as well as the scientist tends to control the erratic behaviour of the project by clearly specifying the conditions under which the given piece of knowledge was obtained. The dream of the scientist is to explain many diverse phenomenon with the help of few concepts and principles, as far as possible.

(h) Executing the project demands not only your talents and tools, but also time. There should be least interference and few social obligations while you are working on the project.

(i) Remember that a project does not always give positive findings or results. Do not be disappointed. At times, the negative findings are equally revealing (Michelson—Morley Expt.).

(j) Executing the project also requires lot of patience, self confidence, perseverence and emotional stability. An experiment tends to go astray wherever it can ! There are many unknown difficulties on the voyage of discovery. Gradually, learn to master them cheerfully even in the face of heavy odds against you. The maintenance of a faithful record of your project is a must: original ideas, good and bad guesses, hits, trials and successes, experiments, even photographs or whatever you deem relevant and useful.

(k) Like a paratrooper, do not jump to hasty conclusions. They will be challenged sooner or later. Clearly state the limitations of your project.

(l) Do not copy or steal other projecteer's ideas, whatever be the temptation.
Resist it successfully, instead, suggest new questions, hypotheses or even insights on the basis of your project work. Clearly acknowledge the ideas or data borrowed or references consulted.

(m) Write a preliminary draft of your project. Show it to your teacher. Do not forget that a project report is written always more than once. Make it readable as well as presentable. Also make a brief summary of your project. Sooner or later your efforts are likely to be recognized.

Lastly, you need not be a strict businessman to extract economic benefit for what you do now or later in science. Disinterested research and financial rewards do not go together. This issue, M. Curie so beautifully expressed which has sense for us in this country as well......"Scientific work must not be considered for the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become, like radium, a benefit for all humanity"[11].

Remember that nobody owes us a living. Like Scientific giants of other nations, we have to learn to be independent in our thought and action. Through the application of science, engineering and technology, we can, unaided, shape beautifully the destiny of our poor people in the midst of rich resources. Science demands our last thoughts and lives. Let us not hesitate at this critical juncture of national adventure ! 'Miles and Miles to go' ! It will, therefore, not be out of place to end this chapter in the immortal words of Prof. Pavlov :

> What can I wish to the youth of my country who devote themselves to science ?

Firstly, gradualness. From the very beginning of work, school yourselves to serve gradualness in the accumulation of knowledge.

Learn the A.B.C. of science before you try to ascend to its summit. Never begin the subsequent without mastering the preceding. School yourselves to demureness and patience. Learn to insure yourselves to drudgery in science. Learn, compare, collect the facts.

Perfect as is the wing of a bird, it could never raise the bird up without resting on air. Facts are the air of a scientist. Without them, you never can fly. Without them, your "theories" are vain efforts.

But learning, experimenting, observing, try not to stay on the surface of fact. Try to penetrate to the secret of their occurrence, persistently search for the laws which govern them.

Secondly, modesty. Never think that you already know all. However, highly you are appraised, always have the courage to say of yourself—I am ignorant.

Do not allow haughtiness to take you in possession. Due to that you will be obstinate where it is necessary to agree, you will refuse useful advice and friendly help, you will lose the standard of objectiveness.

Thirdly, passion. Remember that science demands from a man all his life. If you had two lives that would be not enough for you. Be passionate in your work and your searchings.

What will halt our scientific and technological progress will not be shortages of materials, equipment and even energy but that of bright young projecteers willing to think, develop new ideas and accomplish the best they are otherwise capable of even in the supposed unresponsive environment.

7. Thumb-Nail

Investigative Questions and Project Ideas

The premises of science are taught today roughly in three stages. School science imparts a facility in using scientific terms to indicate the established doctrine, the dead letter of science. The university tries to bring this knowledge to life by making the student realize its uncertainties and its eternally provisional nature, and giving him perhaps a glimpse of the dormant implications which may yet emerge from the established doctrine. It also imparts the beginnings of scientific judgement by teaching the practice of experimental proof and giving a first experience in routine research. But a full initiation into the premises of science can be gained only by the few who possess the gift for becoming independent scientists, and they usually achieve it only through close personal association with the intimate views and practice of distinguished master. In the great schools of research are fostered the most vital premises of scientific discovery. A master's daily labours will reveal these to the intelligent student and impart to him also some of master's personal intuitions by which his work is guided. These ways, he chooses problems, selects a technique, reacts to the new clues and to unforeseen difficulties, discusses other scientists' work and keeps speculating all the time about a hundred possibilities which are never to materialize, may transmit a reflection at least of his essential visions. This is why so often great scientists follow great master as apprentices. Rutherford's work bore the clear imprint of his apprenticeship under J. J. Thomson. And no less than four Nobel Laureates are found in turn among the personal pupils of Rutherford. Some forms of science, such as psychoanalysis, can hardly be transmitted by precept. Every psychoanalyst today has either been analysed by Freud or by another psychoanalyst who has been so analysed, etc. (Perhaps a modern version of the Apostolic succession.) Research in the chemistry of carbohydrates in Britain has been almost entirely the work of four scientists, Purdy, Irvine, Haworth and Hirst, who followed each other in a single file as masters and pupils.

The world we live in is a marvel of man's mastery over his environment. Through the explosive development of the natural sciences, we now predict, control ánd understand phenomena to an extent never fully envisioned throughout the millions of years of human development prior to the current century. The scientific revolution has maximized opportunities for human happiness, and through its technical arms, is providing material wealth and long and healthy lives. New knowledge and the process by which it is obtained, promise a spiritual fulfilment unavailable from the dry bones of fatalism and mysticism.

Fundamental to the conquest of nature by the scientist has been his method of approach to the unknown. Facts and understandings bring the scientist to the frontier but it is scientific methodology that extends the frontier of knowledge.

—Irwin Slesnick

Section A

Introduction

Children are, fundamentally speaking, outdoor creatures. They become unhappy and bored if they are introduced to science for the first time within the confines of the four walls of the crowded classroom. They read science like alphabets from a small book like the one prescribed in Hindi, English or Social studies. Even mathematics is no exception. Consequently, tradition for real understanding and problem solving hardly exists in our schools for they still continue to offer a clerical system of education. In science, the situation was still worse. The teachers themselves were quite ignorant of subject matter as well as methodology of science. They taught science because they were compelled to as general science was introduced in the primary and middle schools of the country in a hurried manner a few years after independence. The situation now, more or less, is the same except a new awareness has dawned : a dissatisfying state of affairs like the current one in the wake of scientific revolution can longer be tolerated !

Investigative questions

We still do not know what sort of questions arise in our children's minds. Perhaps, it is the privilege of the teacher only to ask questions. Secondly, despite our diverse efforts to improve science teaching, children's curiosity, sense of fun and interest are simply short circuited in day to day classroom teaching. Thirdly, no intentional effort has been made to study the sorts of questions children ask at various age levels about the varied aspects of their environment. A beginning in this direction was made by the writer by collecting questions from children studying in Rajasthan, Himachal Pradesh, Haryana, Chandigarh and the C.I.E. Experimental School, Delhi.

Method of procedure

The procedure employed was quite simple. After a brief introduction to the study, 550 pupils studying in the sixth, seventh, eighth classes wrote about 12,000 problems, on specially prepared booklets and which continually agitated their minds. Sixteen teachers after some briefing were also requested to suggest some worthwhile problems on the basis of their classroom experiences for the purpose of inclusion in the curriculum under consideration. They wrote over 300 problems, also on specially prepared booklets. The same procedure was employed to collect problems from primary school students (N=400) ; and the number of problems received from them was over 4000. Due to certain physical limitations, it was not possible to collect problems from their teachers. In both the samples, the boys and girls were just about equal. All the problems were jointly pooled, and on the basis of the following selection criteria, attempt was made to classify the problems in some significant areas of human living. In order to reduce the number of problems, in each category or area of human living, the selection criteria were repeatedly applied after phrasing and rephrasing the problems. Thus a final list of problems was drawn up. It should not be lost sight of that it was not essential that each problem should satisfy all the criteria but care was taken, that as many as possible criteria, were satisfied. In case of doubt, the problem was discussed and the final judgement was made accordingly. The following were the selection criteria :

(a) All problems that were found too trivial, too easy or too difficult were dropped.

(b) All problems that were not directly related to general science were dropped.

(c) All problems that touched the realms of morals, religion and metaphysics were excluded.

(d) All the problems that imparted functional information or useful information, and were characterized by some problem solving activities were included.

(e) All the problems that reflected history of science were included.

(f) All the problems that had a higher frequency of incidence for inclusion were included.

(g) And lastly, all problems were reformulated and the factors of duplication and overlapping were kept to the minimum.

Classification of problems

All the problems after rephrasing were classified in the following significant areas of human living :

1. Our Atmosphere and Weather
2. Our Water
3. Our Food
4. Our Health and Clothing
5. Our Body (parts, care, diseases)
6. Our Living World (plant and animal life)

7. Our Universe and Earth
8. Energy
9. Our Transport and Communication System
10. Science Corner (club)
11. The Wise Use of Natural Resources
12. Science Through Ages
13. Miscellaneous

In each of the above-mentioned areas, the problems were classified at three levels, namely: General problems, Experimental problems and Specific problems. Unfortunately, the study remained incomplete and unpublished for the simple reason that it threw dim light on the detailed elements of the particular environment from which the children came, the typology of problems they encountered at each successive grade; development of techniques for analysing and classifying these problems and the grade placement of these concepts. It is of interest to mention here that the rejected as well as the selected questions of this study reveal indirectly not only children's minds but also the varying scientific content of relevance in their questions. In each of the above-mentioned areas, the problems were categorized at three levels :

(i) General problems. They only seek to impart functional information, and at best, may involve direct close attention and observation in the environment. These problems will orient and reorient the children to a given area and will help them in the reorganization of their floating ideas to a limited extent in a broad area. Experimentation need not be undertaken, essentially in this category. Consultation, discussion and mutual exchange of experience would be the dominant characteristics of teaching approach.

(ii) Experimental problems. The problems mostly seek on the part of the children to find solutions to their problem sexperimentally. They will thus set up hypotheses, test them through control experimentation and arrive at reasonable inferences.

(iii) Specific problems. These problems are of limited character; and mostly involve restricted explanations and interpretations on the basis of the ideas already developed. Those problems which could not be put in the above-mentioned categories were also put in this category.

Questions rejected

These questions have been rejected only in relation to the development of curriculum in general science. This does not mean that the questions asked were trivial or useless. They need to be answered for they not only agitate their minds but also influence their thinking in profound ways. They block thinking in certain areas or at least weaken those concepts on which other advanced concepts are based. Now consider the following questions which, of course, rejected, have lot of relevance otherwise.

General questions

1. Why do we play ?
2. Why do we name days ?
3. Why do we decorate our houses ?
4. What does government do for us ?
5. Why should we worship God ?
6. Why is India fighting against Pakistan ?
7. Why should we obey our parents ?
8. Why do children play with dolls ?
9. Why voting takes place ?
10. What is police ? What do they do ?
11. Why should we chant 'Ram Ram' ?
12. Why do we say 'thanks' ?
13. Why students fail ?
14. India is a big country. Why is its map so small ?
15. Why can't we see the soul ?
16. Why should we learn good manners ?
17. How did Mahatma Gandhi become great ?
18. Where does a dead man go ?
19. How has India changed through the ages ?
20. Who lived in our country before ?
21. Man dies physically. Is it true ?

22. Why are some people vegetarian and others non-vegetarian ?
23. Why did Sita marry Ram ?
24. Why do not the girls keep quiet ?
25. Why is Life Insurance necessary ?

(ii) Questions which are in fact no questions

1. I saw a very beautiful flower or bird.
2. Plants do not grow without seeds.
3. I have a parrot at home.
4. I am a very nice girl.
5. My name is Usha.
6. God lives in the sky.
7. Roots fix the plant.
8. Birds fly in the sky to get food.
9. Man dies when God wishes.
10. India has a capital.

(iii) Question-answer variety

1. Why do we not grow all at once ? We won't get jobs if we grow soon.
2. Aeroplane starts from the airport. It flies in the sky and comes back. Why ?
3. Fields can't be ploughed if it does not rain. Is it true ?
4. Horses used to fly in olden times. Why do not they fly now ?

(iv) Advisory type

1. Do not go to school late.
2. Do you work hard to pass the examination ?
3. Teachers should teach us good manners.

(v) Asking and supplying information type

1. Give the names of five fruits (names are then given).
2. Give the names of five animals (names are then given).
3. Write names of three games (names are given).

(vi) Miscellaneous type

1. Where do the children go whose parents die ? What are those children called ?
2. How did Hindus come into existence ?
3. What is today at your home ?
4. On whose head does our earth rest ?
5. When a man dies, who comes to take him ?
6. Why is Nepal called Nepal ?
7. All of us can speak. When I speak, others do not. Why ? What should I do ?
8. Why does not God die ?
9. How does a man grow rich ?
10. Why is man poor ?

Their evolving minds ask all sorts of questions whose satisfactory answers they hardly received for the very reason that there is no intelligent dialogue maintained between children and their parents at home, as well as young scholars and their teachers at school. They simply believe in teachers' word which they need not challange at the risk of physical punishment. Let us now mention below problems formulated on the basis of enquiries made by the children of grades III to VIII ; and the problems considered desirable for inclusion by some experienced teachers in some significant areas of human living. Let us consider here only one such area viz. Our Living World (Plant and Animal Life).

Our Living World

General problems

1 What makes plants green ; and how does this green colour function in the life of plants ?
2 What are the main classifications of plants ?
3 What are the main classifications of animals ?
4 What is the food of plants ?
5 What is the food of animals ?
6 What plants and animals are harmful to us ?
7 What plants and animals are useful to us ?
8 How did plant and animal life originate on our earth ?

9 How do we distinguish between living and non-living bodies ?
10 How can we check the march of deserts ?
11 How do plants reproduce ?
12 How are plant kingdom and animal kingdom interdependent ?
13 Why do we fail to grow sufficient food in our country ?
14 Why do different trees give different fruits ?
15 Do plants and animals struggle for life ?
16 Do plants and animals suffer from diseases ?

Experimental problems

17 What conditions favour germination of seeds ?
18 What happens when excess of water is given to the plants ?
19 What are the different parts of flowers and fruits ?
20 How do plants and animals differ from each other ?
21 How do insects reproduce ?
22 How diseases spread ?
23 How are fruits and flowers formed ?
24 How plants disperse seeds ?
25 Show that plants are living bodies.

Specific problems

26 Why are the forests so green ?
27 Why can't a cat talk like a parrot ?
28 Why does not cock lay eggs ?
29 Why does snake bite while creeping to the man ?
30 Why do the mosquitoes bite us ?
31 Why are the feet of camels smooth ?
32 Why do not we grow all of a sudden ?
33 Why do not animals speak like us ?
34 Why do the birds fly when we run to kill them ?
35 Why does not tortoise live outside water ?
36 Why germs are invisible ?
37 Why is sparrow so small ?
38 Why do not the roots of the plants go up ?
39 Why has a spider six legs ?
40 Why leaves breathe ?

41 Why can't the plants move ?
42 Why can't the elephants fly ?
43 Why is camel called the Ship of Desert ?
44 Why does fish die without water ?
45 Why do flowers give smell ?
46 Why are flowers of different colours ?
47 Why are flowers attractive ?
48 Why do the off springs of animals adapt themselves quickly to their environments ?
49 Why do we find leaves of different shapes and sizes ?
50 Why do not the plants speak ?
51 Why do not the birds give milk ?
52 Why do some animals give milk and others do not despite the fact that they eat the same kind of food ?
53 Why do some animals reproduce lot of their young ones ?
54 Why do some plants grow taller when cut ?
55 Why do different birds give different calls ?
56 Why do not we have mangoes on a neem tree ?
57 Why do different plants have different rates of growth in the same environments.
58 Why do the eyes of the cat and some other animals shine at night ?
59 Why do the glow-worms glow at night ?
60 Why does the water go up the plant ?
61 Why do we have more bed bugs in summer and not in winter ?
62 Why do animals have four feet ?
63 Why does the snake crawl ?
64 Why all living bodies do not possess teeth ?
65 Why does the lion live in the forest ?
66 Why do the fishes lay eggs ?
67 Why are the leaves of the plant green ?
68 Why does not the snake creep straight ?
69 Why should we water the plants ?
70 Why dead animals and plants decay ?
71 Why can't birds talk to us ?
72 Why do we give manure to the plants ?
73 Why does the dog bark ?
74 Why are the eyes of eagles so sharp ?

75 Why are insects generally attracted to light ?
76 Why can't the owls see in day time ?
77 Why does the snake cast off its skin ?
78 Why are some persons taller and others not ?
79 Why not are all boys always born ?
80 What does the cow eat ?
81 What plants are transplanted ?
82 What type of life occurs in deep forests ?
83 What type of life occurs in deep sea ?
84 What is the difference between flower and thorn ?
85 What plants can grow without seeds ?
86 What is artificial life ?
87 What is artificial respiration ?
88 What are vegetable eggs ?
89 What is moulting ?
90 How does fish manage to swim in water ?
91 How does the blood coagulate ?
92 How life comes in a baby ?
93 How dogs communicate ?
94 How does a camel manage to live without food and water for a long time ?
95 How does one seed give rise to many seeds ?
96 How is it that a given plant gives flowers of different colours ?
97 How did some forests become so dense ?
98 How is curd formed from milk ?
99 How do the fish and other animals manage to live inside a lake when it freezes ?
100 How life develops out of the hatched egg ?
101 How do the plants grow ?
102 How does the green plant grow ?
103 How can we distinguish between good fruits and bad fruits ?
104 How can we improve the quality of eggs ?
105 How is germ formed ?
106 How does a cat see in the dark ?
107 Do we have non vegetarian animals ?
108 Do we have non vegetarian plants ?
109 Do big trees also require water and food ?
110 Do plants and animals possess sense of taste ?

111 Where are the seeds formed ?
112 Where do the germs come from ?
113 Where do the babies come from ?
114 Where do the birds lay eggs ?
115 Can we obtain dyes from plants ?
116 Can we hatch eggs artificially ?
117 Should we use different fertilizers ?
118 Is water essential for frogs ?
119 Which animal lays the maximum number of eggs ?
120 In what ways are animals similar and different from men ?

Concluding statement

Using this simple approach, we selected about six hundred questions suitably grouped into significant areas of human living at three levels, namely, general, experimental and specific. The answers to the various questions supplement, complement and also to a certain extent, overlap each other. It is also possible to group these questions on different basis, say, concept basis. Our study amply indicated that children ask all sorts of questions relating to the origin of things, through principles underlying them to the daily life applications. It is interesting to note that why questions constitute over 42 p.c. of the total questions. And it is not the business of science to supply answers to these questions. It is so because science explains 'how' rather than 'why' of the natural phenomena. What and how questions are just about equal and constitute about 50 p.c. in all of the total questions asked. It gives a lie to the general criticism that our young scholars do not think at all when our analysis indicates that our pupils ask about 8 p.c. of the total questions dealing with highly limited or factual aspects of science. These questions appear to agitate their minds because they do not find their answers in their text books, and even these questions are not discussed in their classrooms. However, these questions will bother them maximally for sometime only ; if science is further taught in an authoritative manner. Like good students, rather than rebels, they must obey the teacher or follow the text book or at best cram answers to the objective type questions[1].

Section B

Introduction

Our environment is full of problems. Even the human foot can be a fascinating object of study. We have made no distinction between an investigative question or a project idea. They are the same sides of a coin. If either of the two is pursued at depth, the entire effort of the projecteer may result in the execution of a successful project. In this chapter, the distinction was made for the very simple reason that these investigative questions were the fore-runners of research ideas for science projects, the latest arrival of Indo-American influence in our country. We have already discussed at depth about ten projects in the preceding chapter. Against the background of those projects, it is quite feasible to work out in detail anyone of the project ideas given below partially, independently and at a reasonable level of accomplishment later on. In the process, many questions or ideas strike but for a limited time. Choose is better than the chase. It should not be forgotten that it is the choose as a result of imaginative chase which gives distinction to any project. In the face of positive failure, suggested lines of inquiry are also equally revealing. Let us now present below about eight hundred suitably classified project ideas already completed as well as sometimes speculated upon by Indian and American projecteers, members of the academic staff of the Science Youth Project, not excluded :

1. Long Essays
2. Point Investigations and Improvisations
3. Project Ideas in Physics
4. Project Ideas in Chemistry
5. Project Ideas in Biology
6. Other Interesting Projects[2]

1. Long Essays

1 The Age of Reptiles
2 Anatomy of the Head
3 The Atom : Man's Primary Concern Today
4 Atomic Reactor
5 Atomic Structure

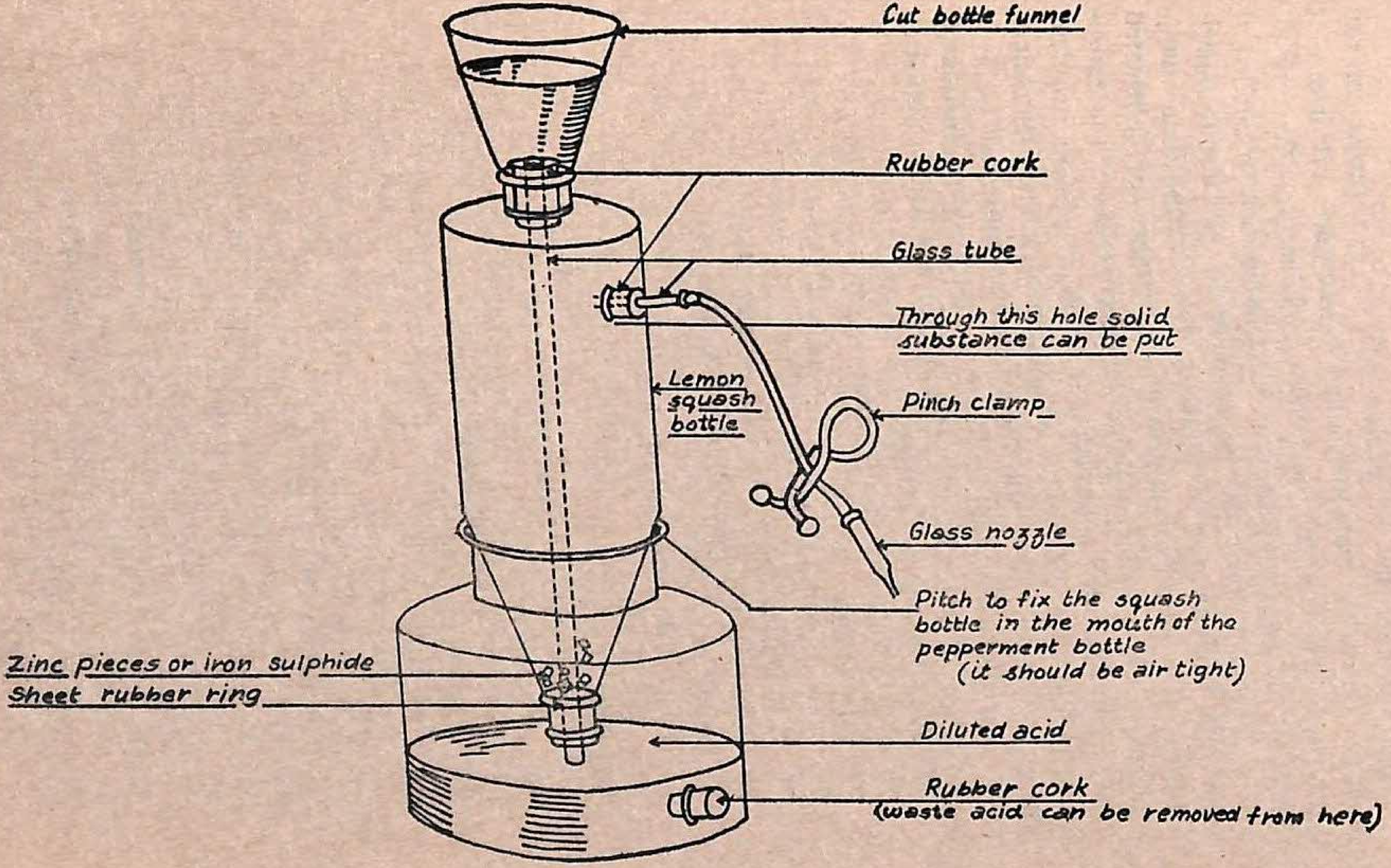
6 Atomic Theory
7 Aviation Hazards and Safety Devices
8 From Battery to Dynamo
9 Cathode Rays
10 Collections and Their Uses
11 Corrosion : Methods of Approach to Corrosion Science
12 Crude Oil by Products
13 Crystal Structure
14 Dairy Industry in Delhi and Punjab
15 Dinosaur
16 The Dispersal of Seeds
17 Diseases that Affect Children
18 Effects of Atomic Blast
19 Electricity in the Service of Man
20 Electronics
21 Essays on Match, Bleaching Powder and Structure of the Atom
22 Flowers-Nature's Most Dainty Plant
23 Fundamental Particles
24 History of the Aeroplane since 1903
25 History of the Development of Man Spectrometry
26 History of the Horse
27 How Modern Mathematics Developed
28 How Modern Science Developed
29 How Plastics are Made
30 Ideas of Bohr About the Structure of Atom
31 Insects : Baby Guys or Good Guys
32 Low Temperature Techniques
33 Magnetization and Molecular Theory
34 Mammals of the Northern Region
35 The Manufacture of Sulphuric Acid Along with its History
36 Measurement of the Charge and Mass of the Electron
37 Modern Periodic Law
38 Modern Science in Dentistry
39 Modern Television
40 Nature of Heat
41 Nature of Light
42 Neutron : An Aggregate of Protons and Electrons
43 Nuclear Reactors
44 Our Enemy: The Termite

45 Our Rich Resources and Poor People
46 Our Wonderful World of Botany
47 Our Wonderful World of Chemistry
48 Our Wonderful World of Physics
49 Our Wonderful World of Tomorrow
50 Our Wonderful World of Zoology
51 Parts of Plant We Eat
52 Prehistoric Animals
53 Products Made From Petroleum
54 Products From Trees
55 Radioactivity
56 Relativity and Quantum Theory
57 Research and Prevention of Plant Cancer
58 Rocket Propulsion
59 Rubber : Natural and Synthetic
60 Shelters Through the Ages
61 Solar Flares and Sun Spots and Their Impact
62 The Solar System
63 Solar Temperature
64 Sources of Clothing
65 Space Flight
66 Stereophonic Sound
67 The Story of Cotton Processing
68 Story of Steel
69 Synthetic Fibres
70 Ultrasonics
71 Using Wasteful Products
72 Wood : To Burn and Build etc.
73 X-Rays
74 X-Ray Powder Method and Lattice Constant of Copper

2. Point Investigations and Improvisations

Kipps Gas Generator

Materials Required : One peppermint bottle, one lemon squash bottle, one bottle with conical neck, glass tubing, two one-holed rubber stoppers, one rubber stopper without a hole and rubber tubing[3].


Cut bottle funnel
Rubber cork
Glass tube
Through this hole solid substance can be put
Lemon squash bottle
Pinch clamp
Glass nozzle
Pitch to fix the squash bottle in the mouth of the pepperment bottle (it should be air tight)
Zinc pieces or iron sulphide
Sheet rubber ring
Diluted acid
Rubber cork (waste acid can be removed from here)

Kipp's gas generator.

This is another list of project ideas. The projecteer can select any one of the ideas mentioned below and work it out at depth like Exposure to Fundamental Scientific Phenomena. One of the many problems, thus formulated, can be tackled at depth. Secondly, the other approach is to read about experiments and equipments and think of fabricating them imaginatively. By collecting data with the assistance of fabricated equipment, it is possible to judge the effectiveness of the equipment. Thirdly, a new approach is to think of a new problem which necessitates fabrication of equipment. The great scientists of past century also fabricated their own equipments. It is a recent phenomenon that industry is supplying sophisticated equipment to the scientists. Now consider the following list :

75 A.C. Voltage Generator
76 Acid Production in the Mouth
77 Adsorption
78 Adventures in Micology
79 Age Dating of Fish Utilizing the Eye Lens
80 Amplifier Combination for Pocket.
81 Analysis of Silver Coins
82 Animal Banding and Marking
83 Animal I.Q.
84 Ants at Work
85 Archimedes Principle : Microscope
86 Ascorbic Acid
87 Assembling a Microscope
88 Assembling a Telescope
89 The Atmosphere
90 An Automatic Door
91 Automatic Railway Signal
92 Automatic Switch of Light
93 The Automatic Traffic Control
94 Automatic Tube-well Machine
95 An Automatic Wilson Cloud Chamber
96 Bamboo as a Reinforcement for Concrete
97 Barkhausen Effect
98 The Behaviour of Soap Bubbles and Films
99 Franklin's Kite
100 Bending of Light
101 Bird Nests

102 Blood Cancer
103 The Body's Emergency System
104 Bouncing Balls
105 Building a Bridge
106 Building a Bird House
107 Build Healthy Bodies and Teeth
108 Building a Modern House
109 Burning of Candle
110 Butterflies
111 Calcium Carbonate
112 Calotropis
113 Catalysis
114 The Characteristic Curves of Diodes and Triodes
115 Characteristics of Soybean Parent and Their Children
116 Chemical Analysis of Water
117 Chemical Gardens
118 Chemistry of Ceramics
119 Chemical Reaction
120 The Chemistry of Inorganic Analysis
121 Chemistry of Magic
122 Chemoreception in Flies
123 Chromogenetic Mutations
124 Clay Modelling
125 Clinical Theraphy
126 Code Sending Oscillator
127 Collection of Bird Pictures
128 A Collision in Two Dimensions
129 Coloured Television Set
130 Composition of Water
131 Concrete
132 Conservation of Wild Flowers
133 Conservation of Wild Life
134 Construction of an Eight-inch, Cassegrainian Telescope
135 Construction of a Microbalance
136 Construction of a Microphone
137 Construction of a Pipe Line
138 Corrosion
139 Corrosion of Iron
140 Corrosion of Metals
141 Cotyledons

142 Craters on the Moon
143 Crystals and Crystal Forms
144 Crystallization
145 Crystals from Petroleum
146 Crystal Radio Set
147 The Cutting Machine
148 The Cutting Machine (How to Improve it)
149 D.C. Motor
150 Demonstration of Principal of Induction Motors
151 Density and Liquid Thrust
152 Dental Creams
153 De-salination of Sea Water
154 Designs for Autos
155 Design of Interior Lighting
156 The Detection of Basic Radicals
157 The Detection of Electromagnetic Waves
158 Detergents
159 Determination of 'g' by Free Fall Method
160 A Device for Finding the Diameter of the Moon
161 Dielectrics
162 Diet to Gain Weight
163 Diet to Lose Weight
164 Diffusion of Liquids Through a Membrane
165 Diffusion Rates of Solids Through Water
166 D. C. Electric Motor
167 Dispersion of Light
168 Drilling an Oil Well
169 Dyes and Dyeing
170 Dynamo
171 Earth's Magnetic Field
172 Earthquake Waves
173 Earthen Pots
174 Earthworms
175 Edison's Light Bulb
176 Effect of Exercise on Metabolism
177 Electric Circuit of a Crystal
178 Electric Elevator
179 Electric Letter Box
180 Electric Motor
181 Electrical Conductivity and Ionisation

182 Electric Motors and Generators
183 To Electrify a Small Locality
184 Electrolysis
185 The Electronic Guard Against Intruders
186 Electroplating
187 Electroplating Alloy
188 Electro-osmosis
189 Electronic Precision Time Trigger Device (Experimental Model)
190 Electronic Timer
191 E-mag III : A Checkerplaying Digital Computer
192 Emergency Lighting
193 Energy : Verification of Laws
194 Energetic Electrons
195 Erosional Agents
196 Evaporation and Rain
197 Expansion and Contraction of Air
198 Experimental Teratology
199 Experimentation in Aerodynamics
200 Experiments on Magnetism
201 Exploring the Arctic
202 Exploring the Fluorescence
203 The Eye Lens
204 Fallout
205 Fire Alarm Thermometer
206 Flow of Electricity
207 Flying Balloons
208 Food Values
209 Forces and Acceleration of an Air Bubble
210 Fur Bearers
211 Fossils and Bones
212 Four-pole Motor
213 The Functional Design of Digital Computer
214 Ganong's Potometer
215 A Gas Generator
216 Gas Tank for Bunsen Burner
217 A Gas Thermometer
218 Gauss Effect
219 Grafting Methods
220 Gravitation Laws

221 Habitat Studies
222 Hair
223 Hair Oils
224 Heat Absorption in Plants
225 A Heater for Boiling Water
226 The Hilsch Tube
227 Home Made Cloud Chamber
228 Home Made Chemical Indicators
229 Home Made Cotton Gin
230 Home Made Flour Mill
231 Home Made Telegraphy
232 How Peas Grow
233 How Seeds Grow
234 How the Telephone Works
235 How and What Animals Breathe
236 Human Foot
237 Humeral Transplants
238 A Hydromechanics Experiment
239 Hydrogen-Oxygen Fuel Cell
240 Hydrostatics
241 Induction Coil
242 Inhibition of Fluorescence
243 Insecticides and Repellents
244 Inside the Earth
245 Inside the Human Tooth
246 Interference
247 Interference Colours in Oil Spots
248 Inside the Earthworm
249 Internal Combustion Engine
250 Internal Resistance of Cells
251 Ionization
252 Lichtenberg Effect
253 Life Cycle of a House Fly
254 Life in the Pasture Land
255 A Light for Emergency
256 Locating Water Wells
257 The Logical Mouse (Computerized)
258 L-shaped Magnets
259 Luminousity of Sources of Light
260 The Main Constituents of Food in Human Diets

261 Magnetic Fields
262 Magnetic Wheels
263 Making Crystals
264 March of Clouds
265 Mechanical Waves
266 Mechanics of Magic
267 Metal Toxicity
268 Microprojector
269 Microwaves
270 Midget Transmitter
271 The Milk Bottle Machine
272 Minerals
273 Mini Fan
274 Mitosis in Onion
275 Model of Earth Interior
276 Model of a Geyser
277 Model of Road
278 Motor Elevator
279 Mountains
280 A Multipurpose Gas Generator
281 Mystery in the Mains
282 One Tube Portable Radio
283 Onion
284 Opaque Projector
285 Optical Illusions
286 Osmotic Pressure
287 Your Own Weather Forecaster
288 Oxidation-Reduction
289 Ozone
290 The Panic Speed of White Mice
291 Paper : Its Manufacture and Properties
292 Percentage of Water in Oil
293 Phases of the Moon
294 Photomagnifier
295 Photoreversal of Ultraviolet Light
296 Photosynthesis
297 Photosynthesis in Euglena
298 Planetarium
299 Plant Germination
300 Plant Movements

301 Plant Pigmentation
302 Plastids
303 Poultry Farming
304 Preparation of Rayon
305 The Principle of an Electric Refrigerator
306 The Principle of a Gas Refrigerator
307 The Production of High Temperature Tentalum Carbide Filaments
308 Psychosomatic Medicine
309 The Pull of Electricity
310 Purkinje Effect
311 Push Button Living
312 Quartz
313 Radar
314 Radioiodine in Guppies
315 Rate of Flow of a Liquid
316 Rate of Respiration in Plants
317 Reaction Engine
318 Reflection of Light
319 Relegation
320 Regeneration
321 Regional Wild Life
322 Reproduction and Concentration of Mutations in Guppies
323 The Rice Mill Model (No Loss of Vitamins)
324 Ring Chemistry
325 Rocks and Minerals
326 Rocks of the Northern Region
327 The Role of Cosmetics
328 Reproduction of Sound (From Cinema Films)
329 Rotary Lobe Pump
330 The Rotatory Motion of a Wheel
331 Rusting Iron
332 Saliva
333 Safe Plumbing
334 From Sap to Syrup
335 Sawdust to Sugar
336 Sea Shells
337 Sea Treasurers
338 Seasonal Variations in Natural Population of Algae

339 Seed Germination
340 Seed Germination (Inhibitors in Nature)
341 Seed and Plant Study
342 Selenography (Surface Geography of the Moon)
343 Semi Conductor and Transistor
344 Sensitivity in Venus Fly Trap
345 Setting up a Model Electric Calculator
346 Sextant
347 A Shadow Box to Show Constellations
348 Showing Phosphorus Uptake by Autoradiography
349 A Simple Apparatus for Verifying Boyle's Law
350 A Simple Radio Set
351 A Simple Windlass
352 Soap Bubbles
353 Soap from Yucca
354 Sodium Hypochlorite
355 Soil Conservation
356 Soil Fertility
357 Solar Cell
358 Soiled Creepers
359 A Solar Heated Green House
360 Solubility
361 Solutions
362 Solar Spectrum
363 Speedometer
364 Splashes and Spatters
365 Sound Absorbing Devices
366 The Sound Barrier
367 Spring Constellations
368 Starch
369 Steam Engine
370 Steam Turbines
371 Static Electricity
372 Stellar Spectrum
373 Strength of Glued Joints
374 A Study of Cilia
375 A Study of Fermentation
376 A Study of Leaf Growth
377 A Study of Microphones
378 A Study of Moment of Inertia

379 A Study of the Moon Craters
380 The Study of Items
381 The Study of Stroboscope
382 Studies on Inactive Life (A Life in Suspension)
383 Subjective Time
384 Sublimation
385 Sulphuric Acid
386 Surface Tension
387 Sugarcane
388 Superheterodyne
389 Sun Pictures
390 Symbiosis
391 Synthetic Rubber
392 Synthesis of Zeolites
393 Table Fan
394 Telegraph Receiver and Transmitter
395 Telephone
396 Telescope
397 The Temperature Control Device
398 Tensile Strength of Fibres
399 Termites in Your Tumblers
400 Test for Nitrogen
401 Testing for T.B.
402 Thermal Efficiency of Insulated Bags
403 Thermoelectric Cooling
404 Thermoelectricity : The Direct Conversion of Heat into Electricity
405 Thief Detecting Device
406 Thin Layer Chromatography
407 Time and Clocks
408 A Time Lapse Photographic Study
409 Titrations without Indicators
410 Tooth Powder
411 Tornado Chamber
412 Toys
413 Traction and Different Wheel Drives
414 Transformers
415 Transistor Radio
416 Transistor Oscillator
417 Turbine Engines for Automobiles

418 UFO (Unidentified Flying Objects)
419 Unilateral Electroplating
420 Unknown Bacteria
421 Unusual Batteries
422 Uses of the Fulcrum
423 Use of Projector for Photoenlargement
424 Using Turmeric as Indicator
425 Vacuum Tube Amplifier
426 Variable Friction
427 Various Methods of Communications
428 Vapour Pressure
429 Vegetable Vitamins
430 Velocity of Light
431 Velocity of Sound
432 Viscosity
433 Visual Inversion
434 Vitamin C in Fruits and Vegetables
435 Water
436 Water Bath
437 Weather
438 Wells
439 Whirl Pools
440 Wind Mill
441 Wood
442 Water Rocketry
443 Wool
444 Zodiac

Section C

Project Ideas
in
Physics, Chemistry and Biology

Introduction

Strictly speaking, it is the job of projecteers to give shape to their ideas through self exploration, thinking and doing. Outside help is necessary and it must be sought for, if really needed.

But getting fed or seeking instruction at each and every stage of the project is quite despicable in the execution of projects. One should, therefore, intellectually respect one's own free wheeling on any problem with an open mind. In the following pages, project ideas drawn from the fields of physics, chemistry and biology are mentioned for stimulating your thought. For the sake of convenience, these have been grouped at three levels, namely, in question forms, phrase forms and complete forms. In the first type, the demand of the problem is in the question form and is therefore, highly specific. In the second, the project has been stated in the form of a phrase ; and it is very difficult to be sure of its varying demands. In the third type, the project has been stated as fully as possible. The title itself clearly delineates the problematic situation. No form of stating the project is either superior or inferior. The particular form of stating the title is an individual projecteer's choice. There is however, a caution that the title of the project should be neither too lengthy nor too short. At the same time, it should possess wide appeal, high elegance and pinpointed preciseness. Now consider the following project ideas :

3. Project Ideas in Physics

Question form

445 Can you develop a device to verify the laws of reflection and refraction other than the one based upon corpuscular theory ?

446 Can you make a light bulb that won't burn out ? (Compare your bulb with standard commercial light bulbs. Record the life and brightness of both.)

447 Can Ohm's law be modified to describe the voltage, current and resistance relationships of conducting solutions ?

448 Can the thermal conductivity of liquids be predicted on the basis of molecular or ionic constituents ?

449 (Electricity has a tendency to leak at high electric pressure.) Can an electric bulb be lighted when placed under electric pressure without any connections ?

450 (Some types of shoe soles squeak when the wearer walks across certain types of floors.) Why? Can some additive be found to minimize this effect?

451 Do all magnets attract things with the same amount of force?

452 Do both ends of a magnet attract objects with the same force? Do both north poles and both south push away or repel with equal force?

453 Does the conservation of Momentum Principle also apply in the case of a collision in two dimensions?

454 Does oily or dirty hair affect the contraction rate of hair due to humidity? How does the human hair compare with hair from other animals in terms of contracting and expanding during humidity?

455 Does paper contain electricity?

456 Does the exact pattern of tyre threads make a difference in the tyre's performance?

457 Should smokers wash their hands before handling tomato plants to ensure the protection of the tomato from tobacco virus?

458 Does the strength of the magnetic force increase or decrease as you move the magnet away from a piece of iron or steel? What is the relationship between distance of separation and magnetic force?

459 (You can use the heating effect of an electric current to measure electricity. Send an electric current through a cold iron wire. Note the change in the wire as it gets hotter.) Does it correspond directly with the current? Are the rates of different metal wires the same?

460 (The specific heat of a sodium carbonate solution varies with the molarity of that solution.) Is this a direct relation? Does the temperature range in which the heating occurs have any effect on the specific heat? Is there any relationship between specific heat of metals and their conductivity?

461 (A simple device can be made to show surface tension and also to measure it.) If we consider that the surface tension of water is 73.05 dynes/cm at 18° C, then, using very small masses (such as equal sections of thin paper),

find the maximum amount of weight that the apparatus resting on the water's surface can carry. Can we relate this weight to maximum masses supported by liquids of other densities? What is the surface tension of various liquids? Does surface tension vary with temperature? If we mix two liquids whose surface tension we know, is there a relationship between surface tension of the mixture and the surface tension of the two component liquids?

462 How much does a human hair contract and expand when exposed to changing humidity?

463 How do samples of sediment collected in stream beds compare, in terms of the size of the grain and the shape of particles, with samples collected from the flooded plain of the same stream?

464 How do different kinds of soil affect the amount of run-off water that results from a thunderstorm or cloud burst?

465 How do the thermal and electrical conductivities of hair compare?

466 How does the number of turns of wire around the iron ore in the primary (the wire with the current flowing through) affect the voltage of the outside coil of wire in which the current is induced (secondary)?

467 How does temperature affect the properties of balls?

468 How does the tensile strength of a rubber band vary with its temperature?

469 How is the density of a substance influenced by temperature?

470 How constant is the A.C. Frequency mantained in your community?

471 (Sometimes thick clouds are seen in the atmosphere; still there is no rain put at all.) How can you make the clouds release rain?

472 Is the climate of northern India changing?

473 Is there a limit to the electrical voltage that can be produced by cells in series?

474 Is there a limit to the intensity of magnetic or electrostatic fields that can be formed?

475 Is there a relationship between the specific gravity of a

liquid and the size of its drop ?

476 What are the sizes of the pores in a plastic membrane? Which solute particles will diffuse through the membrane ?

477 What causes static electricity ? Try rubbing wool, silk, nylon, cotton and rubber with a glass-rod. Do these materials become charged ? Try other experiments with these materials, such as heating, cooling, hitting, etc.

478 What effect does that have on a magnet ?

479 What effect does the length, material, cross-sectional area, and temperature have on the resistance of a wire ?

480 What effect does the rate of moving the magnet back and forth through the coil have on the amount of current produced ?

481 What effect does the strength of the electric current have on the amount of metal deposited by electrolysis ? What effect does the length of time the current flows have on the amount of metal deposited during electrolysis ?

482 What effect does temperature have on the conductivity of various metals ? (Connect a battery to a galvanometer and to a strip of bare wire. Heat the wire.) Is the effect the same on copper, iron and nichrome wire ?

483 What is the difference between lights wired in series and those wired in parallel ? Measure the voltage and amperage at various points in the circuit.

484 What makes an airplane move ?

485 What materials are easy to magnetize ? What materials are difficult to magnetize ? How long will these materials remain magnetized ?

486 What materials can be charged with static electricity ? What materials cannot be charged ? Will materials that can be charged also be affected by a magnet ?

487 At what rates do other materials expand and contract with changing humidity and temperature ?

488 If we use a photometer, we can measure the intensity of a light source. If we assume that the intensity of an electrical light source varies directly with amount of

current, we can also find the amount of current, that is, passing through the light source. What, then, is the relation of the distance between electrodes in a salt rheostat and the amount of current that passes ?

489 If an electric current can be used to make a magnet, can a magnet be used to make an electric current ?

490 A photometer, an instrument used to measure the intensity of light, can be improvised by placing a piece of paper with a small grease spot on it between two light sources. If both sources are moved perpendicular to that screen until the spot disappears, the intensity of one source can be determined, if the intensity of the other source is known by the formula :

$$\frac{L_1}{d_1^2} = \frac{L_2}{d_2^2}$$

Using the photometer and two white candles (whose intensity is usually 2 candle power), and double convex lens, can you find out some relationship between focal length of the lens and intensity of light ? At what distance from the candle should the lens be placed in order to guarantee maximum intensity. What is the relationship between distance and intensity for a double convex lens (include plano-convex, double concave, plano-concave, concave-convex lenses) ? What is the light intensity of the moon compared to a candle or known source ? How does the diameter of the lens affect the amount of light admitted ?

491 Which substances show decrease in volume on heating and increase in volume on cooling ?

492 Why are sparks produced when flint and steel are struck together ? What are the temperatures of the sparks ?

493 Why and how do stones skip on water ? Will stones skip on sand ?

494 Will a magnet have any effect on an electric current flowing through a wire ?

495 Will magnets attract things through paper ? Through tin ? What metals will magnets attract ? What materials will magnetism pass through ?

Phrase forms ; and complete forms

496 The collection, study and classification of some reflecting and refracting bodies.
497 Comparing the energies required to warm and boil liquids.
498 A comparison of rocks based on their specific heats.
499 The conductivity of three main substances in solutions.
500 Conversion of solar energy into heat under different weather conditions.
501 Cooling produced by a room cooler in a given range of humidity and temperature.
502 Design of interior lighting using Laumen method.
503 To determine the best materials for the electric cells.
504 To determine the thickness of the surface of the soap bubbles.
505 The determination of acceleration due to gravity.
506 The determination of Young's modulous of rigidity.
507 On development of drops of different sizes on different surfaces under varied conditions.
508 The effect of moving electrons on radiation.
509 Effect of solute pressure on the boiling point of a certain liquid.
510 Electricity from fruits and vegetables (a method for checking their freshness).
511 EPR spectroscopy at microwave frequencies.
512 My experiments with a leak tester.
513 My experiments with the theories of Mcleoad and Fowler and Grant.
514 My experiments with a mysterious force that serves in many ways.
515 My experiments with pendulum in circular and elleptical orbits.
516 My experiments with waves.
517 Factors affecting electrical conduction.
518 Factors favouring cooling of water in earthen pots.
519 Falling velocity in a liquid.
520 To find the best materials for the electric cells.
521 To find out the velocity of light in different liquid media.
522 Fitting of electricity in houses.

523 A formula for determining the refractive index of a prism.
524 The geological aspects of sands in Rajasthan.
525 The inside of earth in the laboratory.
526 Interesting suggestions for improving classroom microscopy.
527 Intensity of reflected light.
528 Investigating the force of repulsion between two magnets.
529 Investigating the nature of currents through junctions.
530 Luminosity of sources of light.
531 Magnetic effect as a measure of current.
532 Measurement of the distribution of kinetic energies of atomic or molecular velocities.
533 Measurement of viscosity of various liquids.
534 Methods of determining the relative density of liquids.
535 Newton's third law of motion.
536 Observing the lavatory flush tank.
537 Production of heat in electrical resistance.
538 The rate of flow of a liquid.
539 Relationship between thermal and electrical conductivities.
540 Relative density and bouncing (using a rubber ball).
541 Rocket propulsion (attempt at clarification of principles).
542 Measuring small thicknesses.
543 Some interesting experiments in physics.
544 Souping an engine.
545 Static electricity affecting paper.
546 To study the inverse square law and to see how a candle power of bulb is related with the electrical power.
547 To study the motion of a projectile.
548 To study the nature of potential drop between the electrodes of simple voltaic cell and corresponding loss in weight of the zinc plate.
549 Strength of electromagnets.
550 Study of the combined magnetic field owing to a magnet and the earth's field.
551 A study of the tensile strength of kraft paper before and after the addition of sizing agents.

552 A study of water drops.

553 Studies on the effect of change of pressure on electrical resistance of carbon dioxide.

554 The suitability of water as boiler feed.

555 An appratus to measure angle of elevation and depression; and thus to assist in judging the heights of high objects and distance between two objects ; and similar other projects.

556 Construction of a moving magnet, attraction type, gravity controlled, scale spread, low power loss, low price milliammeter and its standardization, graduation and calibration.

557 Determination of the relationship between the actual height of a ball from the ground before dropping and the height of the same ball after reaching the ground.

558 To establish a relationship between the different currents passed through an electric bell ; and different lengths of waves produced by them in a fixed length of twine connected to the clapper. Hence, to find an unknown current by the length of the wave it produces.

559 Explanation of increase in the rate of evaporation when air is pumped into a liquid in terms of kinetic energy possessed by the molecules of the liquid.

560 To find the effect of heat on an electrolyte and establish a relationship between the temperature of the electrolyte as well as the mass deposited on the electrodes.

561 Relationship between cooling produced by room cooler and outside temperature ; and cooling and outside humidity.

562 The relationships between the thermal conductivity of a metal and its temperature, density and electrical conductivity.

563 To prove that relative density of a substance is inversely proportional to the bouncing of a rubber ball which is filled with that substance ; and to calculate the relative density of different substances by the application of this law.

4. Project Ideas in Chemistry

Undefined problems

564 Analyse the different fruits to determine percentage of water and carbon, and identify the basic and acid radicals.

565 Collect the different stone pieces of same weight from your locality, put them into equal quantity of the same acid solutions of same strength (say N/20). Find out the quantity of liberated gas and the time taken for the reaction.

566 Determine the amount of AgCl formed by precipitating it out from different samples of common salt.

567 Determine the amount of free alkali in different soaps used for washing purposes.

568 Determine the melting point of a substance by mixing it with :

(a) cooling mixture, (b) adding organic liquid in which it is soluble :

(i) which has higher B.P. (ii) which has lower B.P.

569 Determine the quantity of H_2 evolved by the same quantity of metal Zn, Mg, Al with the same volume of HCl of same strength.

570 Determine the rate of evaporation of liquids (benzene, carbon tetrachloride, acetone) and establish relationship with their boiling points.

571 Determine the rate of rusting when iron pieces are kept in vapours of pure water, ordinary water, solution of an electrolyte and saturated solution of CO_2.

572 Determine the rate of diffusion of $KMnO_4$; and find out whether Graham's law is applicable or not.

573 Estimate the amount of glucose in the leaves of different plants.

574 Find out the change in B.P. of water by putting different quantities of soluble salts in it. Repeat the same with :

(a) insoluble salts, (b) putting ice into it, (c) mixing with organic liquids of higher B.P. (d) of lower boiling points.

575 Find out effect of temperature on the acidity of the fruit juice (different juices).

576 Find the pH of soil from different locations in your village. Titrate the soild with a base or acid of known strength. What other common chemical tests can be done on soils ?

577 Investigate the effect of vapours of different acids and bases on rusting of iron.

578 Like Cu, other metals can also displace Ag from AgNO$_3$ solution. Estimate the quantity of liberated Ag from the solutions of same strength and equal volumes of AgNO$_3$ by the same quantity of different metals.

579 Litmus paper can be made by boiling strips of red cabbage and let them stand for about half an hour. The liquid can then be used as an indicator. You can soak duplicator paper or filter paper strips in coloured water and let dry. Try making other indicators by using blue berries, different flowers and other plants and vegetables.

580 Prepare the solutions of various bleaching substances and investigate then the effect on the strength of the fibre.

Question forms

581 Can an alloy be made of a metal and a compound, e.g., lead and lead oxide or nickel and cobalt chloride ?

582 Can effects of nicotine be avoided in tobacco without removing the nicotine from the plant ?

583 Can you collect the vapours from a candle flame and change them into a solid ?

584 Can you determine the temperature at which different chemicals in solution will crystallize ?

585 Can you make your own photographic paper and take photographs with it ?

586 Does magnetized iron have different chemical properties than unmagnetized iron?

587 Does the pH of a water solution affect the germination of seeds ?

588 Does tobacco plant contain the same proportion of nicotine from seedling to its full size ?

589 How can rusting of iron be prevented ?

590 How does iron rust ?

591 How can you distinguish among different fibres ?

592 How do various ions affect the colour of borax when heated in a hot flame ? (Make a small loop, wrapping the end of a piece of nichrome wire around the end of a sharp pencil. Insert the other end of the wire into a piece of cork. The cork will serve as a handle. Heat the wire loop and dip the loop into melted borax to form a bead. Touch the bead in a very hot flame. You can use a blow pipe with a spirit lamp. The colour of the bead when cold compared to the colour when the bead is hot is used to determine the metal.)

593 How many grams of water can be absorbed per gram of blotting paper, newspaper, and book paper ?

594 How small is a molecule ? (Dissolve a gram of potassium permanganate in 100 cc of water. This gives a solution of 1 to 100. The colour is due to $KMnO_4$ molecules moving around in the water. Remove 10 cc of this solution and add to it 90 cc of fresh water. You now have a solution of 1 to 1000. Can you see the colour ? Repeat this with several additional bottles of water. Be sure always to take your coloured solution from the bottle containing the weakest solution. Can you still see the molecules after you have diluted the solution to 1 to a million parts ?)

595 Is carbon monoxide slowly oxidized to carbon dioxide by atmospheric oxygen ?

596 Is there water in petrol, spirits, vinegar and sweet oil ? (Copper sulphate is a test for water.)

597 Is it true that a solution with a pH of seven is less irritating to the skin than are the solutions of higher or low pH values. The pH of human blood is 7.2.

598 What effect does the amount of surface area have on the rate at which a substance dissolves in a liquid ?

599 What are some of the effects of high pressure on chemical sustances ?

600 What change, if any, is observable in the chemical make-up of rain from one rain storm to another ?

601 What effect does temperature have on the formation of crystals ?

602 What effect has the rate of evaporation on the forma-

tion of crystal ?

603 To what extent does the natural acidity of wood increase the corrosion of iron filings under damp conditions ?

604 What gives colour to the flame produced by coloured matches ?

605 What is the concentration of H^+ ions (pH) for the same solution of H_2SO_4, HCl and HNO_3, carbonic acid and oxalic acid ?

606 What kind of a soap detergent gives the most suds ?

607 What is the effect of increasing the amount of current on the rate at which water breaks up during electrolysis? Will A.C. assist in electrolysis ?

608 What is the relationship between electrodes and the amount of current that passes in an electrolytic solution ?

609 What liquids are colloids ?

610 Fermentation of carbohydrates is a common process for producing ethanol. What strain of yeast is capable of producing the highest concentration of alcohol ?

611 Why does the odour of coffee differ from the taste of coffee ?

612 Why does lime water turn milky when exposed to carbon dioxide ?

613 Which acid is the best conductor ? Does the conductivity depend upon the H^+ concentration ? What molar solution of NaCl provides the best conductivity ?

Phrase forms

614 Acidity of juice in tomatoes.
615 Acidity of lemon juice.
616 Analysis of red rock deposits in Trivandrum district.
617 My attempt to classify metals differently.
618 A comparison of certain methods of finding solubility.
619 Comparative study of the properties of halogens.
620 Crystal and flame colour.
621 Determination of molecular weight of volatile liquids.
622 Determination of total hardness of water.
623 The detection of some basic radicals using filter paper method.

624 Electrolytic decomposition of titanium.
625 My experiments with electrolysis.
626 My experiments with the theories of Macleod, Fowler and Grant.
627 Factors affecting electric conduction of a solution.
628 Investigating the combustion of a burning candle.
629 Molecular weight by lowering freezing point.
630 Molecular size and two other related studies.
631 Need to classify metals (a personal unfinished experimental approach).
632 On studying the various types of water.
633 Precipitation of ferric hydroxide solution.
634 Preparation of colloids and the comparison of the precipitation values of colloids.
635 Protection of brass by the formation of a chromate.
636 Qualitative aspects of tin and its ions.
637 Quality of ground water in western U.P.
638 Removal of rust and scales from ferrous stores.
639 Refractometric study of complex formation between metal ions in solution.
640 Rusting of iron in the atmosphere of alkali solutions.
641 Some problems and interesting experiments based upon chemical reactions.
642 Studies on the nature of double salts and complex salts.
643 Studies on the oil of Nahor seeds.
644 Systematic analysis of an unknown ore.
645 Titrations without indicators.

Complete forms

646 Biodegradability of sodium alkane sulfonate based detergents.
647 The corrosive action of the oil of semecarpus anacardium (marking nut).
648 Demonstration of pH of certain substances by the method of indicators.
649 To determine the effect of temperature on diffusion rate.
650 Distribution ratio of iodine between water and carbon tetrachloride.
651 Estimation of the number of water molecules in oxalic

acid ; percentage purity of commercial sodium carbonate, dissolved salts in sea water, and estimate of the percentage purity of commercial copper sulphate.

652 To find the chemical changes taking place in the ripening of banana.

653 To find out the percentage of alkali content in soaps.

654 To find out the rate of attack of concentrated sulphuric acid on certain metals.

655 To illustrate different types of valencies in ordinary chemical compounds with special reference to water.

656 Inorganic analysis by means of HS_2—quinol calthorate crystals and their alcoholic solutions.

657 An investigation of the chemical reasons for the corrosive action of the oils of semecarpus anacardium (marking nut).

658 An investigation of the effects of organosilicone derivatives on alkyl aromatic sulfonates.

659 A new ion exchanger and elution of Cu^{++} ions from it.

660 On the NaCl content of common salt and its relationship to solubility.

661 Oxidation-reduction ; and investigations into the corrosion of iron.

662 Paper chromatographic separation of copper and iron. (An investigation of the dependence of R_f value on acid-concentration.)

663 De-salination of sea water.

664 A study on the suitability of myrobolan waste for making activated carbon.

665 To study the rates of movement of ions in solution on the application of emf.

666 To test, study and analyse different samples of Bhilai water (natural, distilled, soft (boiler feed) and drinking).

667 To verify and justify the identification of sulphuric acid.

5. Project Ideas in Biology

Question forms

668 Are chemically induced tears the same as those induced emotionally ?

669 Can emotionality resulting from maternal factors be modified by clinical therapy ?

670 Do insects see colours ?

671 Do people make their best physical and mental efforts when alone or with other people ? Does competition have a stimulating or depressing effect on people ?

672 Do seeds digest starch ?

673 Do the stomata close in a dust storm or in rains ?

674 Does aspirin in water prolong the show-life of cut flowers ? Can other substances be found to accomplish this ?

675 Does everyone exhale the same amount of air ?

676 Does osmotic pressure increase as the temperature of a given solution rises ?

677 Facial vision is a term used to explain a person's ability to avoid walls and other obstructions at night or when blindfolded. How accurate is a person's facial vision ?

678 How are chemicals used to kill weeds in crops ?

679 How do ants follow the trail of other ants ? Is the trail memorized by the ants or are they orientated by light ? Do they smell the trail ? Try destroying and making trails with formic acid.

680 How does the blood clotting time of various animals compare with humans ? (To determine the clotting time, heat a piece of glass tubing. Pull the ends apart, so you have a length of fine tubing. Sterlize the tip of your finger with spirit. Prick with a needle. Place the glass tubing over the drop of blood. The blood will rush up the tubing. Examine a small bit of the tubing every 15 seconds. When you observe fine threads being formed, this is the blood clotting time.)

681 How does the change in osmotic pressure due to temperature compare to the change in osmotic pressure due to differences in concentration of the solution ?

682 How does a young leaf grow ? Mark a square grid on the surface of a young leaf with India ink. Observe the growth over a few days.

683 How human being perceive depth.

684 How long do animals live ?

685 How long does it take mosquitoes to digest blood ?

You can see the red colouration of blood through the swollen abdomen of a well fed mosquito.

686 How much pressure and heat can be developed by germinating seeds ?

687 How plants grow in different soils.

688 How a tooth decays.

689 How will recovery times be effected under conditions of repeated fatigue in a frog's leg muscle ?

690 If a plant is deprived of the food making capacity many of its leaves yet still retains those leaves, can it remain healthy ? What will happen to those leaves which are deprived of sunlight ?

691 If the temperature of an enzyme increases, does its rate of activity also increase ?

692 Is bacteria found in the air ? In the soild ? In water ? On animals ? On yourself ? (Check by growing bacteria cultures on slices of potatoes. Expose one section to the air for one hour and add or touch other slices to the other media. Cover. Examine after two days.)

693 Is fat fatal ?

694 Is there such a physiological phenomenon as a "second breath" ? To what extent is the "second breath" a psychological development ?

695 Is your cat a south paw ?

696 Should the stems of roses be cut back in the fall after frost, in the spring before the emergence of new growth, or never.

697 What are the effects of adrenalin and accetylcholine on the beating rate of a frog's heart ?

698 What are the effects of increased stimulating voltage on the reactions of a frog's leg muscle ?

699 What are the effects of increased temperature on the respiration of a cockroach ?

700 What are the effects of increasing stimulus duration on the reactions of a frog's leg muscle ?

701 What are the pigments in a leaf ? What are the effects of soil condition upon the presence of these pigments ?

702 What are the sizes of the pores in a plastic membrane?

703 What birds migrate to and from your geographical

areas? What birds pass through your geographical areas during migration and are not permanent residents?

704 What can you see with a microscope?

705 What do you know about tadpoles?

706 What foods contain fats? (Crush food materials and drop some in the bottom of a test tube. Cover the food material with a few drops of carbon tetrachloride. Let the material stand for about ten minutes and then pour a few drops on a piece of white paper. After the carbon tetrachloride has evaporated, examine the paper. If the food contains fat, there should be a transparent grease spot on the paper. Remember, carbon tetrachloride vapours are dangerous to breathe.)

707 What is the absorption spectra of chlorophyll?

708 What is the average heart beat of students in your room? Does the average heart beat change with age? What effects do different amounts of activity have on the heart beat? What is the average heart beat of different animals?

709 What is the effect of carbon dioxide on plant growth? Will plants live in an atmosphere of pure carbon dioxide? In an atmosphere of no carbon dioxide?

710 What insects have the power of breaking off their body parts? Which ones can regenerate these parts? Does regeneration of legs occur just in the young insects or can adults do it too?

711 What is the effect of environmental temperature on the metabolism of man?

712 What is the effect of light intensity variations on the opening of the stomata of a leaf?

713 What is the effect of oxygen on plant growth? Can a plant live in pure oxygen? In air lacking oxygen?

714 What is muscular fatigue? How can we demonstrate it?

715 What is the effect of yeast on fermentation?

716 What is the optimum sugar concentration in which pollen grains will germinate?

717 What is the rate of growth of roots and where is the

growing region on the root ? (Mark off a young root with India ink and keep moist. Observe every day.)

718 What is a reflex ? Under what conditions can a reflex be observed in a frog ? How do these conditions lead us to an understanding of the physiology of a reflex 'arc' ?

719 What is in a log ?

720 What is the walking order of the legs of various types of insects ? How does the insect modify his walking pattern with removal of one or more legs ?

721 When other variables are constant, how does digestion of various substances progress through time ?

722 In which colour of light do plants grow the best ?

723 Which organisms in water seek light ? Which avoid light ? (Cover 3/4th of a narrow mouth jar with dark paper. Allow it to set for two days in moderate light. Examine the dark portion and light portion under the microscope.)

724 Which seeds grow the fastest ? Line the inside of a glass or jar with several layers of newspaper. Place several different types of seeds between the glass and paper. With the glass half filled with water, observe the sprouting of the different seeds.

725 Why do popcorn and to a lesser degree, other varieties of corn pop ?

Phrase forms and complete forms

726 Bacterial resistance to antibiotics.

727 Cancer induced by the rous sarcoma virus.

728 Catabase in living plant materials.

729 Conditioned reflex in earthworms.

730 Effects of chemicals, auxins, light on plants.

731 Effect of drug dexedrine on the metabolism of four vertebrates.

732 The effect of egg, white and tears on bacteria.

733 Effect of growth promoting substances on vegetative growth in plants.

734 Effects of light variation on plant growth.

735 The effect of magnetic field on snails.

736 The effect of magnetism on yeast cells.

737 Effects of nutrition on white mice.
738 Effect of pH on enzyme action.
739 Effect of prolonged light on plant growth.
740 Effect of temperature on the rate of breathing in frog.
741 Effect of temperature on starch digestion.
742 The effects of temperature on the toxicity of insecticides.
743 The effects of weather on man.
744 The effect of varying concentrations of detergents on the survival of fish.
745 The effects of a vitamin deficiency on blood serum proteins.
746 Environmental effects on plants of the sutter buttes.
747 Growing algae in various bands of the spectrum.
748 Further investigations in chemoreception in flies.
749 How pinto beans grow ?
750 How shrimp hatch and grow ?
751 Modification of plumage colour in domestic pigeons.
752 Physical environmental control—the effect of altitude on the albino rat.
753 Protective effect of serotonin against gamma radiation.
754 What foods have starch ?
755 Unusual land snails in Madhya Pradesh.
756 Use of statistics in botany.
757 The comparable effect of growth promoting substances in soybean seeds to commercial gibberellin on ratican gardenias.
758 Development, isolation, and analysis of unknown growths of nitrogenated rye grass.
759 The dependence of human resistance to electricity on physiological factors.
760 To determine the standard deviation in the total shoot length and fruit production in tribulus terrestris collected from different sources.
761 The effects of artificial and natural sunlight on plants.
762 Effect of bodyweight, sex, starvation and pithed brain (suprae-osophagealganglia) on the oxygen consumption of cockroach, periplaneta americana.
763 The effect of coloured lights and coloured backgrounds on chamaleons.

764 The effect of different factors on the nervous system of a cockroach.

765 The pituitary influence over frog colouration.

766 Effect of the drug dexedrine on the metabolism of four vertebrates.

767 The effect of an electric field on the growth of seedlings.

768 The effect of light on endogenous rhythms.

769 Effect of light, temperature and crowding over the appearance of mosquito imago from the pupil condition.

770 Effect of white and far-red light on mitochondrial respirations as a new explanation for photomorphogenic phenomena.

771 Effects of thyroid removal and stimulant upon the reflex speed of albino rats.

772 Effects of various chemicals on the rates of regeneration in hydra.

773 Isolation and characterization of three bacteriophages of genus pseudomonas.

774 Findings on the simultaneous production by cells of an anti-viral agent (AVA) and a halo-producing factor in response to inactivated viruses.

775 A method of obtaining a complete balance of life within a closed system.

776 The protein content of two different fungi growth with different sources.

777 The reaction of drosera intermedia to certain chemical and physical stimuli.

778 The study of factors like temperature, light and crowding on the appearance of mosquito imago from their pupil condition.

779 A study of the firefly and the chemical nature of its bioluminescence.

780 A study of the effect of growth regulators on rooting of bryophyllum calycinum.

781 A study of the effect of tranquillizers on the metabolism of white mice.

6. Other Interesting Projects

782 Evolution of porphyrins in fossils.

783 Find the acidity of acid and acid in simple voltaic cell which gives maxium current and amperage.

784 How to find out the thickness of the penetration of ink on a writing paper.

785 A preliminary study of the variation of mechanical waves with depth of water and with different concentrations of different types of solutions.

786 Relationship of atmospheric pressure to precipitation.

787 Stoichiometric doping of intermetallic thermoelements.

788 To study how the strength of paper varies with its thickness and when it is drenched with some different liquids.

789 A study of three sites in M.P.

790 Ultrasonic detection and ranging applied to an auto-frog safety detection system.

791 Variation of velocity of effluse of a liquid with pressure.

792 How the water table rises and lowers.

793 Analyse the working force either of your locality or village in which you live.

794 Do certain questions agitate you or your classfellow ? Make a list of at least fifty such questions.

795 Make a list of at least five topics for writing long essays as well as at least ten project ideas which appeal to you most.

796 Prepare a suitable questionnaire for determining the main areas of interest of your classfellows or entire school community.

797 What is project work ? Does it hamper learning science at school ? What difficulties are experienced by your science teachers as well as young projecteers in carrying out project work ? Prepare suitable questionnaire and interview schedule for this purpose.

Concluding statement

Our environment is full of investigative ideas and problems for the youngsters. Science is full of partial ideas to tackle them. In day to day classroom teaching, it is the job of science teachers to help their wards see several problems of varying difficulty and interest. For example, if he is teaching that a magnet has two poles, he should not forget to pose, say, the following problems :

1. Is it possible to have a magnet of one pole alone ?
2. Can a magnet possess more than two poles ?
3. What is the difference between an electric pole and a magnetic pole ?
4. If a magnet points in the N-S direction, does it invariably point in the same direction ?
5. At other times, are there any statements in the text-book which you can challenge easily ?
6. Is it possible to verify Boyle's law on the cheap ?
7. Is it possible to design a single apparatus which prepare effectively several gases for physical and chemical testing ?
8. Is it possible to fabricate this costly equipment ?
9. Given observations, is it possible to suggest alternative explanations ?

There are some of the preliminary ways of 'Shaking the Scientific Tree.' The scientific tradition of ingenuity never fizzles out despite the presence of vast body of scientific knowledge. Let us illustrate by quoting a few examples. Thomas Hunt Morgan, a well-known scientist and also a noble prize winner, hypothesized that acidity in sea water remarkably influenced the fertility of those creatures which lived deep in the sea. He did not have any acid at hand. He got a lemon and squeezed a few drops of it in his aquarium. He created history by showing that 'small changes in chemical environment greatly affect the fundamental life processes of fertility'. A. Van Allan, the discoverer of radiation belts, successfully launched his rockets at high altitudes only when he 'clustered some heated orange juice cans around the firing mechanism of his next rocket package'. P. Feynan, another noble prize winner, became a great advocate of microminiaturization. He publicly offered a prize of one thousand dollars to any one who would get him an electric motor of 'no more than a quarter millionth of a cubic inch in volume'. Many inventors speculated, came and showed him flea sized electric motors. One day, one engineer, William H. Millenan, surprised Feynan by showing him a synchronous motor 'no large than a dust mote', under his microscope. Professor Weld Peabody, a patient of cancer, died while delivering a talk on the 'Care of the Patient'. He wrote in detail earlier about the growing symptoms of his fatal disease even on the day he died[4]. It is interesting to note that the American Miscellaneous Society (AMSOC) encourages its members to think as erratically and madly as possible by recognizing their efforts for 'dynamic incompetence, distinguished obscurity and unwarranted assumptions'. Not long ago, one of its active members had a brain wave and suggested that a hole about twenty miles deep be dug not only with a view to 'reveal billion of years of Marine Evolution but also to clarify the processes by which the earth, its oceans and continents came into existence.' The more he asserted the idea and its scientific implications, the less fantastic the suggestion became. The efforts of AMSOC bore fruits when a test bore of 600 ft deep was dug under twelve thousand feet of water off California. Now designs are available which promise holes as deep as ten miles[4]. To understand as well as to control nature is the central function of science ; and the time consuming aim of scientists. Project ideas, if suitably formulated by the practising scientists, can go a long way in firing the constructive imagination, in all its varied aspects, of our young projecteers. To quote Herbert Spencer :

> ......That a drop of water, which to the vulgar eye is but a drop of water, loses anything in the eye of the physicist who knows that its elements are held together by a force which, if suddenly liberated, would produce a flash of lightning ?...Think you that the rounded rock marked with paralleled scratches calls up as much poetry in an ignorant mind as in the mind of a geologist, who knows that over this rock a glacier slid a million years ago ? The truth is, that those who have never entered upon scientific pursuits know not a tithe of the poetry by which they are surrounded[4].

8. The Other Frontiers

The nature of the training that one receives in an average Indian home is well worth a close inspection. An average Indian child and even a young man or a young woman is continuously advised by their elders. They are subjected to one of the most negative processes (as confirmed by a UNESCO study conducted some time ago). Their attitude to accepting or discharging responsibility is reduced to unquestioned obedience or an occasional display of rebellion against authority.

What does an Indian child, or youth learn at home ? Here is a sample of parental guidance if one may call it so : "don't do this," "don't do that," "don't go there," don't come here," "don't read that," "don't meet him," "where are you going and why ?" "why have you come so late ?" "with whom were you talking ?" "don't mix with him," "you will not take this study or that course in the college", "ask your grandfather what career he would like you to pursue," "consult your mother," "take permission from your father," "you cannot see this picture," "don't read this book but get that book," "you will not marry her," "show some respect to your elders," "behave yourself," "do as you are told." etc., and so on...

It is an extraordinary situation, wherein practically in each Indian home we play generously what can be described as the "blame game". If anything goes wrong in the house, then the father blames the mother ; the mother the son ; the son the sister; the sister the servant; and the servant the master. If something does not take place, as it was expected to, hours are wasted every day of one's life in blaming someone else. Nobody has the courage to be bold enough to accept the fact that something has gone wrong and that it has gone wrong because of him. People are shy to come forward and acknowledge boldly their mistakes. It is indeed remarkable how in the administrative and public scene of our country, we notice this practice being indulged in most freely. We find that the "blame game" is being played on a nation-wide scale. The politicians blame the civil servants ; the civil servants the politicians ; the higher civil servants blame the civil servants below them ; and the latter their seniors. A businessman blames the administration ; the administration blames the businessman. The consequences of such a situation are not only ludicrous but even pernicious. Even Jawahar Lal Nehru, who himself was the Chairman of the Planning was now and then heard saying : "Some thing is wrong with the Planning Commission : it needs to be reformed"

—Satish Chandra

In the conditions of modern life, the rule is absolute : the race which does not value trained intellegence is doomed. Not all your heroism, not all your social charm, not all your wit, not all victories on land or at sea, can move back the finger of fate. Today, we maintain ourselves. Tomorrow science will have moved forward yet one more step, and there will be no appeal from the judgement which will be then pronounced on the uneducated.

—A.N. Whitehead

Unless we start . . . with the individual nature of the learning process and the varied needs of the individual children, and relate our means and methods in a thorough going way to this, we are producing but palliatives. It means placing the emphasis on learning, not teaching, on the provision of incentives and occasions and materials for learning rather than on teaching methods and skills. The role and skill of the teacher is then not less important, but it is different and certainly not less difficult.

—Prof. Tibble

Introduction

In the preceding pages, we have discussed at depth the nature of science, the nature of scientific enterprise, logical thinking and problem solving, science as past adventure, exposure to fundamental scientific phenomena, investigative questions and project ideas ; and varied illustrations of scientific methods through some illustrated specimen projects without giving the definition of : What is a Project ? Within recent years, this term has become very popular both with the students and teachers but in the process has suffered from multiplicity of meanings. At one end of the spectrum, it means doing something, that is, even maintaining a note book containing some observations other than the prescribed experiment one, with the preparation of improvised apparatus in the middle, and systematic attack on the problem reflectively at the other end. As science is devoted to discovery, the execution of a project therefore reflects the investigative aspect of science. A project, therefore, is nothing but a small or large scale genuine adventure, theoretical, practical, mixed, historical or essay type, into a territory unknown to the projecteer at the beginning of the project. For obvious reasons, projects undertaken by scientists and the projecteers are similar but not identical. Still the motives may remain more or less the same. This aspect of science is in a state of utter neglect, practically speaking, in all the developing countries. To put in other words, getting brilliant young boys and girls involved into the investigative aspects of science is our main problem. Its solution does not solely depend upon added expenditure alone because the latter does not automatically solve or as well define our problems. In the act of carrying out projects, the projecteers gain in several ways. They have familiarity rather than memorized knowledge of facts and concepts, acquire functional rather than limited skills in practical work, find opportunities of demonstrating their ingenuity and originality, and consequently, learn to acquire, first hand, scientific knowledge, skills, attitudes, interests and appreciations. They gain in personality traits as well : self confidence, persistence, emotional stability and tolerance. On getting training this way, they need no longer depend upon the availability of fishes because they have now acquired the art of catching fishes. This is a right step towards Self Education or Education for Understanding. A.K.C. Ottoway echoes Piget fairly well when he says that a 'large part of modern education consists in arranging suitable situations in which learning can take place ; in which the learners are, in a sense, the teachers, in so far as they teach others or teach themselves'. Regarding other frontiers, we discuss the following issues in this chapter ;

1. Stress on Productive Thinking

2. Science Youth Project.
3. Science Clubs.
4. Science Exhibition.
5. Reporting and Judging of Projects.
6. School Library.

1. Stress on Productive Thinking

How do you judge a cow ? Not by the amount of grass she eats but by the quantity of milk she yields! This popular saying has lot of relevance in this country because in the name of maintaining high standards, lot of subject matter is being down graded with little concern for what the students do or will do with these massive dozes of information. There is a psychological angle to this serious problem as well. In this area, we have only questions but no specific answers for guiding our thinking and action ; for interest in this branch of knowledge, is just of recent origin. But still, the current status of the situation has to be seen in a different context, that is, the behavioural objectives of science teaching and learning. All will agree here that in the present age of science and technology, purely factual or information packed lessons are of limited value for achieving the behavioural objectives of science teaching. Specimen under study is of less importance than the method and attitude toward investigation and inquiry with which its study is approached. Information about it has to found out rather than spoon fed by the teacher, say, for the examination of the specimen. This approach, if employed, will foster self confidence, security of integration, intellectual honesty and courage, thinking (critical creative and intuitive), productive hypotheses (both open and narrow) and leaps to tentative conclusions waiting for their testing, verification and application. To quote J.R. Suchman :

> ......large amounts of practice in exploring, manipulating and searching. The children should be given a maximum of opportunity to experience autonomous discovery. New goals must be set for the children. Instead of devoting their efforts to storing information and recalling it on demand, they would be developing the cognitive functions needed to seek out and organize information in a way that would be the most productive of new concepts. Both the teacher and the pupil would have to be cast in new roles,

The pupil must become more active and aggressive in his learning role. Direction of the concept formation process should come to regard his environment (including the teacher) as a potential source of information which can be obtained through his own acts of inquiry. The teacher must abandon his traditionally directive mode and structure an environment, that is, responsive to the child's efforts at inquiry are rewarded by success, that the child is able to obtain the information he needs, and that he does discover new concepts on his own. The teacher can also coach him in the techniques of data collection and organization that will lend power and control to his searching. The educator should be concerned above all with the child's process of thinking, trusting that the growth of knowledge will follow in the wake of inquiry with the only proviso that they do rapidly return to the starting point with a high degree of rationality bringing with them the gains of their regression to 'primitive and fantastic modes of thought'. Among them only, those who show talented behaviour like prolonged pursuit of an interest, great amount of time devoted to an interest, active search for information and ideas, multiplicity of related interests in the field, self initiated interests or concerns, accumulation of an unusual degree of skill, understanding, capacity for abstract, thinking, extraordinary memory, intellectual curiosity and persistence in worthwhile behaviours will benefit the most from such an inquiry built in programme undertaken in a conducive environment[1].

To concretize, this would mean that physics teacher won't be 'profferring observational facts about heat, electricity, optics, sound and mechanics' but on the other hand, he would plan the teaching-learning process in such a manner (intuitive approaches allowed) so as to guide 'a study of wave mechanics and the structure and behaviour of particles'. In biology, he will study 'genetic continuity, change of organisms with time, relationship of structure and function, relationship of the organism and environment and organismal response to environmental stimuli rather than teaching the anatomy and physiology of representative types of plants and animals along with special topics in conservation, health and growth'. We will go a step further by suggesting that more and more opportunities be provided to the pupils to pursue an investigative question, suiting their mental development, right to its logical end. We have discussed this problem at depth in the two preceding chapters. Imagine now the difference that will make in our science teaching, if approached this way, and the impact it will make on the thinking and action of our students. They will know that science is a branch of knowledge in which the elastic limits for meeting the demands of the rebels working against the established modes of thought are, practically speaking, infinite. For them, science will then cease to be an 'intellectual computing machine'. On the other hand, they will find it an exciting 'slice of life'. To quote Stephen Toulmin :

> Like all great critical activities, science has not one, but a number of related aims : it must try to satisfy these as far as possible in harmony, and it is entitled to take on fresh aims. Any activity so varied in scope has, inevitably, a history with many phases : many legitimate enquiries had to be undertaken before the modern tribunal of experimental verification could have its present-day relevance. There is room in the scientific activity today also for men of many talents. Speculative imagination, scrupulous honesty, mathematical command, logical perspicuity, as well as experimental inventiveness and ingenuity : these are all relevant to the manifold aims of science, in its broader sense. Here we see the most serious defect in the predictivist account of science : it gives the false impression that the possibilities are closed. Once before, in Hellenistic times, scientists came to see their task as restricted to mathematical forecasting : what followed was disastrous. For most of us, nowadays, the task of understanding nature is a wider one. Prediction is all very well ; but we must make sense of what we predict. The mainspring of science is the conviction that by honest, imaginative enquiry we can build up a system of ideas about nature which has some legitimate claim to 'reality'. That being so, we can never make less than a three-fold demand of science : its explanatory techniques must be not only in Coperinicus' words 'consistent with the numerical records' ; they must also be acceptable — for the time being, at any rate as 'absolute' and 'pleasing to the mind'[2] !

2. Science Youth Project

A highly imaginative and exciting project was conceived, planned and executed in two stages at the Regional College of Education, Ajmer in the latter part of 1965. The planners visualized to build research and innovation into our school science education as part of the science club activities, still an optional activity in our school, Dr. Irwin Slesnick, a science consultant attached to the Regional College of Education, designed and developed a Mobile Science Show to focus science students' attention on the investigative aspects of science. The main aim of this show was to demonstrate both to science teachers and students some fundamental scientific phenomena, illustrate these phenomena with adequate number of investigative questions and thereby to develop among the vast body of science students a real feel for science ; and ultimately to acquaint them with the real nature and philosophy of science : scientific methods in particular. This Mobile Science Show toured whole of Rajasthan in 1966-67. Since then, it has visited the other three Regional Colleges of Education and given shows at the summer institutes held for science teachers right throughout the country. On the basis of this experience, two associates of Dr. Slesnick, K.C. Goyal and Piyush Swami have published a book : 'Research Ideas for Science Projects' which is available free of cost from the Principal, Regional College of Education, Ajmer [3]. The main weakness of this show was that our science teachers were not in a position to undertake this type of work because it was all new to them. It was, therefore, felt that a training programme for science club sponsors was a must before the inherent ideas of the Mobile Science Show as advocated by Dr. Slesnick and his two associates could be translated into action. For furthering this end, Regional College of Education, Ajmer obtained a grant of Rs. 2,00,000 from the USAID through the National Council for Science Education to initiate a two weeks training programme for over two hundred science club sponsors to be selected from the northern region for the year 1968-69. The first training institute began on August 19, 1968 at the Regional College and the Science Youth Project came into existence.

Aims and objectives

The purpose of this training programme is to build quality into the Science Club Movement (which in fact needed a shot in the arm) which was initiated by D.E.P.S.E. in 1957-58. The main aims of the training programme are :

(i) To provide opportunities for developing more competency in organizing, executing and evaluating science clubs, science fairs and science exhibitions.

(ii) To promote the use of the discovery and investigative approaches to science.

(iii) To encourage the use of library facilities in developing investigative type problems.

(iv) To provide advice to science club sponsors during and after the institutes.

(v) To help develop in participants various skills such as carpentry, metal work, glass bending and specimen collecting[4].

Training programme

It is spread over two weeks and consists of lectures on science clubs, investigative projects in various branches of science, the mastery of research operations, practical training in laboratory and workshop skills (construction of improvised apparatuses included), and preparation and completion of investigative projects. It is of interest to mention below some examples of the investigative projects undertaken and completed by the participants at the first two institutes :

1. To study the immersion of cylindrical can varying the depth of orifice from the free surface of liquid (water) and keeping the area of cross—section same throughout.
2. To investigate substances found in the cells of different plant materials.
3. To investigate the displacement tendencies of metalions from the solution of their salts and to develop the idea of chemical activity series.
4. Chromatography of the pigments of various parts of the plants.
5. To determine the standard deviation in the total shoot length and fruit production in tribulus terrestris collected from different localities.
6. To investigate the temperature difference for which

thermoelectric current generated in different thermocouples is maximum.

7. How is the magnetic field strength of an electromagnet affected by the cores of different substances ?
8. Absorption of minerals by plant leaves.
9. Displacement of metals by placing metals in metallic solutions.
10. How much time and weight is required for the drying of glue to give the strongest possible joint ?
11. To investigate the effect of addition of alcohol to the saturated solution of some of the electrolytes.
12. To investigate digestive enzymes in the alimentary canal of animals (cockroach).
13. Verification of Boyle's law without the use of mercury.
14. To investigate the critical radius of capillary tube for turbulent motion of water.
15. Study of foaming power of soaps and effect of different soaps on fabric.

Impact

It is expected that after undergoing training, the participants will help their student to select those projects which share most of the following features :

1. They should reflect some forward thinking and action on the part of the students, i.e. they should go beyond the textbook.
2. They should illustrate scientific principles either from the pure science or applied science.
3. They should be based upon adequate number of scientific skills.
4. They should show originality as well as complexity and be in keeping with the mental development of children.

5. They should make use of inexpensive materials as far as possible.

6. They should not take unnecessary long time to complete, otherwise the projects may be left in disgust by the students.

7. They should not be too delicate to handle. On the other hand, they should be well constructed as well as attention getters.

It is then hoped that perhaps the quality of science fairs will go up through the participating science clubs as a result of this training programme.

3. Science Clubs

Science club movement in India is of recent origin. It began in 1957-58 under the auspices of the D.E.P.S.E. which assisted financially to the true of Rs. 1200 per science club in the country. There are over 900 science clubs in the country today out of which only a few are very active. Men, money, material, motivation, follow up programmes, sympathetic attitude of the headmaster and the inspectorate and recognition etc. are some of the factors which were not effectively exploited to boost this movement in the past. To a restricted extent, the economic situation of the country has not been favourable to the development of this movement in general and the establishment of science clubs, on voluntary basis, in particular.

Aims and objectives

Science club is a 'simple word for a complex notion' which connotes activities of varying complexities. Given the will and resources, an ambitious programme for various categories of students can be developed. In fact, it has the potentiality to become a nucleus of science teaching and link classroom and laboratory activities with the community. It won't be an exaggeration to add that the various outcomes of science education can be achieved through formal and informal activities of the science club. Sponsor's Guide Book, a publication of the N.S.T.A., states the following general aims for the science clubs :

(i) To learn about science, science careers, and the opportunities, responsibilities, and important role science plays in our democracy.

(ii) To explore interest and abilities of members in relation to the various fields of science.

(iii) To cultivate in members the qualities of personality, character and leadership which are essential to scientists.

(iv) To learn how and where scientists receive their training, its cost, the scholarship available, the number of years required and the academic prerequisites and standards.

(v) To study the lives and the influence of great scientists.

(vi) To stimulate interest in and interpret science to others.[5]

These aims have sense for us in this country. Even guiding function in relation to vocational ambition and aspiration is also included. The various outcomes of science education mentioned in this book can be achieved through formal and informal activities of the science club.

It is least visualized that the varied activities of the science club are of great help even to the school counsellor for guiding function in relation to vocational ambition and aspiration in our country as well. Except for seeking clarifications in relation to progress made, our problem should not be to do hair splitting on the aims and objectives of science clubs. It is, on the other hand, to translate part of these aims into partial achievements. In our view, for a developing country like ours, the following can be set as the aims and objectives of science clubs:

(a) To develop among students the general awareness of science and the role of science in social affairs.

(b) To train students in the use and practice of science methods through investigative questions, problems and projects. Stress will be on environmental studies.

(c) To develop among students certain scientific skills : manipulative, communication and concrete.

(d) To expose students to fundamental scientific phenomena; and thereby to expect certain standards of work from them.

(e) To develop among students scientific interests in various branches of science.

(f) To prepare students for effective participation in science fairs and exhibitions at different levels. Stress will be on the preparation of models and charts and the development of school museum.

Science club is an evolving activity. Other aims and objectives can be added later on.

Activities

There is no fixed list of activities. As far as possible, these should be based upon the students' interests and aptitudes. A teacher should float varied ideas off and on. To put in other words, he should not force his ideas and interests on his students. Science club activities are and should remain voluntary. Examples of activities which can be carried out by the students are :

(a) Organizing lectures, extension lectures and symposia etc.

(b) Paper reading for the club members on various topics of scientific interests. This will also include project reporting.

(c) Activities or interests relating to the survey of community resources (field trips).

(d) Organizing science exhibitions and participation in science fairs.

(e) Conducting investigative projects and preparing models and charts.

Organization

One of the science teachers at school will organize it. He should meet all the science students informally emphasizing the importance of science club. All interested students should meet at a convenient hour and discuss the formation of the science club. An ad hoc committee may be set up to solve problems on the way : seeking headmaster's permission for the formation of the club and requesting him for providing certain physical facilities, purchasing or borrowing of tools for the club, students share in collecting the raw materials, membership fee, and the day and time for the science club. Our experience tells us that it is easier to start the science club with lectures and reading papers as the attendance in that case is generally fine. Hardly more than 10 p.c. of the students are interested in advanced project work. Rest of the members will prefer to spend their time on charts, models, preparations like candles, soap and hair oils etc., setting up simple experiments and bottling plant and animal life. Those with theoretical interests will be interested in the general nature and history of science. Further, our experience tells that a teacher need not necessarily operate the whole constitution with a big bang on the opening day. The number of offices should be few. It is also our view that these few offices should not be filled in a hurry. On the other hand, he who contributes most to the philosophy and action of the science club should be the student president or secretary of the science club. It is always better to start in a small way and then grow big.

Tools

A small workshop at the school is essential. Its equipment depends upon the financial as well as other physical resources available, to a great extent, it also depends upon the type of investigative projects attempted as the school under the guidance of the science teacher. So tools may be purchased as and when found necessary. The work can start with a sum of twenty rupees. Other services can be borrowed as paid for. Now consider the following four lists of tools each costing twenty rupees, forty rupees, eighty rupees and two hundred rupees[6].

A. *List of Tools Costing About Rs. 30/- Approximately*

1. Hand Saw 18″	1 No.
2. Claw hammer	1 No.

3.	Screw driver 8″	1 No.
4.	Plier 6″	1 No.
5.	Try square	1 No.
6.	Two feet scale (wooden)	1 No.

B. *List of Tools Costing About Rs. 60/-*

1.	Hand Saw 18″	1 No.
2.	Claw hammer	1 No.
3.	Screw driver 8″	1 No.
4.	Plier 6″	1 No.
5.	Wooden plane 10″	1 No.
6.	Hand drill with bits	1 No.

C. *List of Tools Costing About Rs. 120/- Approximately*

1.	Panel Saw 18″	1 No.
2.	Claw hammer	1 No.
3.	Screw driver 8″	1 No.
4.	Plier 8″	1 No.
5.	Try square 6″	1 No.
6.	Jack plane (wooden) 10″	1 No.
7.	Hand drill with bits	1 No.
8.	Marking gauge	1 No·
9.	Hack saw	1 No.
10.	Coping saw	1 No.
11.	Firmer chisel ½″	1 No.
12.	Mallet	1 No.
13.	Wood smooth file 10″	1 No.
14.	G. clamp	1 No.

D. *List of Tools Costing About Rs. 300/- Approximately*

1.	Panel saw 18″	1 No.
2.	Claw hammer	1 No.
3.	Screw driver 8″	1 No.
4.	Plier 8″	1 No.
5.	Try square 6″	1 No.
6.	Jack plane (wooden) 12″	1 No.
7.	Hand drill with bits	1 No.
8.	Marking gauge	1 No.
9.	Hack saw	1 No.
10.	Coping saw	1 No,

11.	Firmer chisels ¼", ½", ¾" and 1"	4 No.
12.	Wooden mallet	1 No.
13.	Wood smooth file 10"	1 No.
14.	G. clamp 6" opening	1 No.
15.	Combination oil stone	1 No.
16.	Bench vice 6" jaw	1 No.
17.	Bevel square	1 No.
18.	Steel scale 24"	1 No.
19.	Wing compasses 8"	1 No.
20.	Wood rasp file 10"	1 No.
21.	Triangular file 6"	1 No.
22.	Mortise chisels ⅛", ¼", and ⅜"	3 No.
23.	Firmer gauges ½" and 1"	2 No.
24.	Snip 10"	1 No.

4. Science Exhibition

It is a window on the quality of science teaching going on within the precincts of the school. It also helps to publicize the school as well as recognize the efforts of the young projecteers. It is a matter of pride to know that a group of British boys of the Kettering Grammar School in England 'beat the Kremlin by half an hour in announcing the latest Soviet manned space flight (Soyuz-11)'? Even the highly trained scientists of the Jodrell Bank could not help congratulating these young adventurers for being the first in the West to pick these signals. It has been an exhilerating hobby for the projecteers at the school since 1960 under the guidance of the able science teachers. Earlier, with the assistance of their ammature tracking station built in the school science laboratory, they had also the distinction of picking up for the signals of the Chinese satellite. It should not be lost sight of that the equipment used was not at all sophisticated but simple and within the reach of many schools. Our boys can also do this provided their imaginations are fired with similar problems in any area of science. The science exhibition, therefore, provides a forum where talents and tools of our young projecteers can be assessed and recognized. The science exhibition serves the following purposes :

1. It exposes students as well as laymen to a wide spectrum of scientific phenomena,

2. It, specifically speaking, cultivates the interests of students in the various branches of science.

3. It provides vast opportunities to develop and show various personality traits, for example, initiative, ingenuity difficulties, persistence and self confidence in the face of difficulties.

4. It encourages science students to fabricate small pieces of various apparatuses, models and charts imaginatively, thus promoting competition of talents and tools in the process.

5. It leads to the acquisition of advanced scientific skills.

6. It broadens the outlook of students in other branches of science.

Preplanning

A stitch in time saves nine is a popular saying. This also applies to the effectiveness of any exhibition; and hence the relevance of preplanning. The following variables can be considered at the preplanning stage : availability of physical facilities ; the nature of cooperation to be sought from other institutions and teachers ; background work required for executing and presenting new and newer investigative projects ; demonstration experiments and models etc., selection of activities which not only provide fun and entertainment to the visitors but also significant and worthwhile current scientific information ; obtaining imaginative entries from students and scientific products from the community, and lastly obtaining cooperation from other departments of the school. While planning at this stage, a few important points should not be lost sight of. The exhibits made by the students, however, imperfect these may be, must be preferred to those which are not their genuine work. Secondly, as far as possible, the club members should be allowed to participate creatively in the organization of the science exhibition. This decentralization of work will influence their personality positively for they will as well know how to handle failure, and more, the best possible improvisations when circumstances run counter to their expectations. Thirdly, a few interesting and entertaining experiments must be set up to attract laymen and children. Fourthly, the student demonstrators must be trained and tested several times before they are actually asked to explain any project, exhibit experiment and even chart. Lastly, attempt should be made not only to decorate the exhibition tastefully but also involve science teachers of other schools in several varied ways, for example, appointment of judges, request for delivering talks, requests for talking to their own students about the salient features of the exhibition. In other words, this means to give wide publicity to the exhibition by sending invitations to pupils' families, science teachers, school administrators, district officials and even newsmen[7].

5. Reporting and Judging of Projects

Reporting

Report writing is a skill which again is a matter of practice. It is a written means of communication; and hence great care should be taken in preparing the final draft. In fact, it is a great help to get the preliminary draft read and corrected by at least two or three persons. At least, one of them should be an expert in language. For giving a bird's eye view, it is also a good habit to give a brief summary as well as an abstract of the project. It is only then a good project report is ready for acceptance either in the Vigyan Shikshak or School Science. If judged of inferior quality, it can be published in the school magazine. It then serves a local purpose. The following suggestions should be kept in mind before writing the report so that the report contains what it is supposed to contain. Lastly, there is no standard format for writing because the final form of the project report depends upon the nature of the problem investigated. Now consider the following suggestions :

(a) Use of simple language. Science has its own vocabulary but if the report contains too many technical terms, the report becomes less effective. Paragraphs loaded with highly specialised language can be understood by experts only. Such reports will not be useful for every person who is interested in the subject. It is necessary to use technical terms at essential places, but the overall report should be simple.

(b) Write precisely and explain ideas clearly. Sometimes the reports are overworded. This not only wastes space but also results in the poor understanding of the project report. A good report, therefore, communicates in unambiguous words what the investigator intends to convey. The report should be precise but not too precise to understand it. A balanced situation is the solution. This can be done if investigator puts himself in the situation of a reader. If he finds a little difficulty in understanding any idea in his first draft, it means that some more work has to be done to reshape the entire draft on the basis of above principles, the project can be reported in any form. Although majority of scientists have adopted a format for reporting their results, this could be changed to suit the individual problems.

(c) Statement of problem. The problem should be written in exact and specific words. No further explanation of the problem is necessary here, but any details about the plants or chemicals on which the study is made should be included.

(d) Introduction to the problem. Under this heading, reference to previous researches can be made briefly. Few words can explain the reason or the concern of investigator for the particular problem.

(e) Hypothesis. The principal intellectual instrument for a scientist is the hypothesis. Many hypotheses may arise in the mind of investigator and his main work is to think of an explanation to accept or reject a particular experiment. These explanations can be based on experimental results or rational judgements. The function of an hypothesis is to indicate new experiments and observations. A relevant discussion on hypothesis brings reader closer to the problem. The investigator should convince the reader in favour of his conclusions.

(f) Materials and methods. The discussion on the tentative and more likely correct hypothesis should be followed by a detailed description of materials used and methods employed. The description should be so exact and so complete that it enables any one to repeat the experiment. If the special apparatus is made for the experiment, giving the details of its construction are necessary. The different arrangements in the apparatus can be shown with the help of a photograph or diagram.

(g) Observations. All observations taken dur ing the experiment should be reported. The appropriate use of tables and pictures will simplify the summarization of observations. If terms are used, these should be clear, simple and free from mistakes.

(h) Interpretation of data. After collecting observations, the various interpretations should be made. Different graphs or step by step mathematical calculations make it easy to put forward the idea clearly. If any help of previously known formula or theory is taken, a complete reference should be made at the place.

(i) Main conclusion. The interpretation of data leads to a few statements of conclusions.

(j) Limitations. It is always good for author to point out any flaw in the experiment himself than waiting for any other person to point out the weaknesses. All the limitations of the conclusions and sources of error should be reported. The investigator knows the weaknesses of experiment and he should readily mention these at this place unhesitatingly.

(k) Striking observations. If something is unrelated to the particular experiment under study, but quite significant otherwise, it should be reported. Often such observations have led to important discoveries. The discovery of diabetes, the way of spreading of cholera, etc., were made on the basis of side observations. The correct reporting of such observations may give a clue for better explanation of the same problem.

(l) Problems for further investigation. A good project is one which leads to further researches on the same topic. A list of such problems that may have struck the investigator as side problems while pursuing his main problem should be reported at the end.

(m) Bibliography. All references which were used during work should be listed. If the reference is a book, it should state author, title, publisher, date, place of publication and pages. If magazines are consulted, it should state author, title of the article, name of magazine, date and number of issue and page numbers.

(n) Acknowledgements. Briefly, all the acknowledgements should be made in the end. Most reports can be fitted in the above format but investigators are free to modify it according to individual problems. For example, a project in mathematics may be reported in a different way from the projects in physics or biology or chemistry[8].

Judging

It forms a very important aspect which has escaped attention. Poor judging will result in the poor execution of projects. There is, therefore, a need for educating judges on this score. The following proforma developed as a result of discussion with the participants of the various summer institutes of the Science Club Sponsors held at the Regional College of Education is given below. It is marked out of 100 marks and has the following aspects, namely, Scientific Approach (20 marks); Originality (30 marks); Skill and Workmanship (20 marks); Display (15 marks); and Personal Interview (15 marks).

	Marks
(a) Scientific Approach	20
(i) Principles involved	5

(ii) Orderly collection of data	5
(iii) Scientific thinking	5
(iv) Accuracy	5
(b) Originality	30
(i) Planning	10
(ii) Execution	10
(iii) Use of materials	5
(iv) Considering class levels	5
(c) Skill and Workmanship	20
(i) Good workmanship	10
(ii) Neatness	5
(iii) Proportionate size	5
(d) Personal Interview	15
(i) Understanding principles	10
(ii) Interpretation	5

If necessary, other aspects can be added and corresponding weightage given. It is a healthy practice to publicize this weightage because it tells the projecteers how to score high on their projects[7].

Concluding statement

Science, engineering and technology are in the news these days. They are influencing us, our society and environment in so many diverse ways. It is for this reason alone that attempt should be made to familiarize our embryo citizens at least with the nature of scientific enterprise for the knowledge of content (which is limitless), of course, necessary is not sufficient. They ought to experience science for some time in its multi-varied aspects : selected products of science having relevance to their lives, processes of science, aims of science and scientists as people. The execution of a project, therefore, goes a long way in familiarizing them with the methods and procedures of science. They get abundant opportunities of their choice to develop their intellectual acumen and personality traits. They see the irrelevance of cramming facts, concepts, definitions, equations, and constants etc. simply as aids to pass the examination. This impact is all pervading which in turn influences their general outlook in other branches of knowledge including personal behaviours. They tend to see science, conceptually rather than factually, that is, far beyond the dates of Panipat battles and the name of places and kings. They also see that they are not being educated in science if they are only taught about the working of the television without the basic notion of electron. Further, they also learn 'how to learn' in an area which is the least controversial : science. The demands on the future scientists are going to be more stiff. We in this country will be deceiving ourselves if we continue to downgrade subject matter or increase its bulk or lump without paying any serious attention to the structure of the subject. Science as experience or in 'search of meaning' or as a 'mixture of fact and fancy', foolhardiness and crankness, not even excluded, is an 'attempt to make children see science steadily and to see it as a whole; to enable them to assimilate scientific principles and methods by a consideration of phenomena from the point of view of every relevant branch of science; and to increase their capacity for intellectual pleasures by opening to them the inexhaustible pleasures which science discovers in the world of everyday life' (Halmyard). It is only then that the achievement of the behavioural objectives at the highest level takes place among the projecteers who in their turn x-ray their own evolving concepts more penetratingly even at the cost of tolerating quite a bit of vagueness in their forward march of discovering new knowledge and techniques. In this process, they measure themselves against tasks set, an exercise which leads to self discovery of one's own innate potentialities. If their potentialities lie in the field of science, blessed are they, for they are our potential fluid thinkers who will challenge established knowledge at the most opportune times. A gain for themselves, their country, and the world at large! It is only thus our concept of the physical world (more or less permanent) changes profoundly over the years.

Science is a mine of ideas for the development of engineering and technology. The latter can't progress in the absence of such ideas. It is the projecteers, later on, turned scientists who will supply such ideas for exploitation through research and development commercially to technologists. The inventors can pick up their ideas independently so we need projecteers of all types : mathematicians (working with paper pencil), scientists, technologists, engineers and inventors to serve the cause of Advancing Scientific Enterprise in our times. A few of them may get interested towards the fag ends of their lives in the philosophy of science. We have in this country hardly a couple of philosophers of stature specialists in the philosophy of science. There is a need for such personnel. To quote R. Sonne Cohen :

> Philosophy is a persistent attempt to grapple with foundations, when foundations are shaken, philosophy is practical and urgent. When the times are revolutionary, then the effects upon philosophy are revolutionary too. And when the foundations of scientific knowledge undergo revolutionary transformations then the philosophy of science receives extraordinary challenge. If the challenge is met rather than dimissed, the reciprocal effect upon scientific thought can be productive and liberating. The effect upon scientific education can be similar. But the way to liberation from old mental habits is through thickets of problems, tough and thorny.

It is the job of the schools to take up a new role as centres of inquiry in the context of the demands made on them in the closing half of the twentieth century. They have to act as centres of inquiry or agents of change rather than remain satisfied with the current status of preparing their wards for passing the annual examination. It should only be a part of the general aim which strengthens national vitality or leads to national rejuvenation in the highly competing international market. Otherwise education then, largely speaking, ceases to be investment into man. The maintenance of age old object poverty in the midst of rich resources is a great slur on our intelligence and the manner in which we train intelligence unreflectively in the country. Our problems of food, shelter, clothing, defence, and in short, economic development should not dishearten us but instead, challenge us to solve them creatively with the help of science and technology. As a great physical giant, our country needs not implore for head-space under the global tent but raise its sights, both qualitatively and quantitatively, on distant horizons. To quote A.C. Joshi :

> Piecemeal reforms of science education will not produce the desired results. What is needed is a well concerted plan. It is often said that a scientific temper should be created. It will give a tremendous fill-up to science education. At the same time, only science education imparted on a gigantic scale promotes the scientific temper and modern out-look in a country. Science education is to play a very vital role in transforming Indian society into a modern society. The occasional apprehension heard in the country against the dissemination of science and the use of modern technology are based on ignorance of what science really is. Juxtaposition of the claims of sciences and arts in education has no basis, and the much talked about dehumanisation is not so much the outcome of scientific and technological progress as poverty, starvation and insecurity which science helps to remove. There is no danger to our culture and spiritual values by the advancement of science. On the contrary, only the material development it will bring by increasing the stock of trained scientists, engineers and skilled labour can preserve our society[9].

Our country should give a big call with a helping hand to her sleepy projecteers who will change her economic face positively beyond recognition in the fore-seeable future. The All India Science Teachers Association and the NCERT have given such a clarion call in the past. It is now for the science teachers and other agencies, particularly speaking, the Press to give such a call as intense as the family planning slogans. Or, alternatively, the nation should advertise its biting problems, like the electrification of Paris, in the eighteenth century, for their theoretical and practical solutions to the younger minds. If carefully built and handled into our educational and social set up, investigative projects will surely make impact in a big way on our teaching-learning science ; away from cramming facts in learning an exciting subject like science with the inherent possibility of changing the scientific and technological face of a tradition bound society crying for modernization in the wake of Second Industrial Revolution. Let projecteers dream and work that way at the breaking of dawn. When grown up, they will find their own conducive environment, as far as possible, unaided, whatever be the eclipsing factors, temptations or tendencies of escapism, for they have mastered the stimuli rather than the restraints. How Children Discover Knowledge brings their little nascent dreamy insightful worlds closer to their brainy heads, confident legs and clever fingers for executing firm strokes successfully over the years on joints of problems (Plato) inventing, creating and acquiring in the process, new concepts, insights and skills leading to scientific discoveries and techniques, nay even beyond, for they will, strictly speaking, cease to be 'intellectual computing machines' but find science as the very 'slice of life' (Stephen Toulmin) from which it emerged thousands of years ago and to which it will return in the age of exploding knowledge (J.D. Bernal) in the not too distant future. What then is the inhering central message of this book ?

Get a little away for you are obstructing their vision of science in the making. Expose them to fundamental scientific phenomena with a view to let them share first hand experiences of intellectually honest scientific ecstacy as well as frustration of what it means to investigate a simple scientific problem experimentally in the face of preliminary successes or failures. Try to uncover rather than cover science by treading on unbeaten tracks, at least, for some of the time in day-to-day science teaching. Help them to develop their own hardiness or edge in thinking by motivating them to turn, return and again turn inside out on their own schemata (F.C. Bartlett, Jean Piaget and R.R. Skemp) or self-loop problems (J.S. Bruner). Let them find that it takes time to give as well as judge tentative findings even on a simple scientific question at the always incomplete cathedral of science, reason being that every sound scientific argument is 'shot through PERHAPSES, and MAY BES and HEMMING and HAWING' (Rudolph Flesch). It is only then the transductive perceptual structures evolving continuously constitute a coherent whole in the phraseology of the Geneva school. It also illuminates the very basis of science to teachers and their students by prompting and encouraging them to master more stimuli rather than more restraints or what it looks like acting like jokers in the development of science while trying hard to reach destination with or without direction by developing friendship with confusion on the way—for major scientific advances take place only when the most funny or utopian concepts are woven or left over partially by joining part fragments to each other like fibres in a long rope through 'feats of imagination and originality' (Linus Pauling) or graded acts leading to partial discoveries (Irwin Slesnick). It is in them that his personality is disintegrated and rationality raised sky high. Thus, he is born time and again in his pupils.

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3. Contributed by Piyush Swami and K. C. Goyal, Science Youth Project, Regional College of Education, Ajmer.

Chapter VI

1. Courtesy : Shri S.B. Singh, Lecturer in Physics, Regional College of Education, Ajmer.
2. Executed by Laxmi Das and J. Padh, Sardar Multipurpose Higher Secondary School, Jodhpur.
3. Executed by A. Ghafoor, Govt. Higher Secondary School, Doongla (Chittorgarh).
4. Quoted from the Young Scientists, Department of Education in Science and Mathematics, NCERT, New Delhi, Courtesy : Prof. M.C. Pant.
5. Executed by S.K. Hawa, Currently Lecturer in Chemistry, Government College Ajmer for the Science Youth Project.

6,10. Executed by two Science Talent Search Examination Competitors, Courtesy : Prof. M.C. Pant.

7. Executed by D.P. Gupta, Govt. Higher Secondary School, Ramsar, Ajmer.
8. Executed by Miss Shobha Bhat, Formerly a Student of the Regional College of Education, Ajmer.
9. A Project Report, Quoted from Vigyan Shikshak, AISTA, April-June 1969.

11. Oliver, H.P.H. ; The way of Discovery. Ibid.

Chapter VII

1. The writer conducted three incomplete studies on children's questions.

2. Abstracted from
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   - (ii) Rao, C. S. (Ed) ; Science Teachers Handbook, American Peace Corps, Hyderabad, 1968.
   - (iii) Courtesy : Professor Irwin Slesnick and Dr. (Mrs) S. Thornton. They supplied the relevant material on project ideas in abundance to the writer.
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5. Quoted from sponsors (FSA) Guide Book, a NSTA publication, Washington, U.S.A.
6. Contributed by B.S. Singh, Craft Teacher, Govt. Higher Secondary School, Topdara, Ajmer.
7. R.N. Karnawat, Lecturer in Physics, organized two discussion sessions on the organization of science exhibitions and the development of the score card for the evaluation of projects as well as exhibits. These talks were also published in the Activities for Science Club Sponsors, Department of Extension Services, Regional College of Education, Ajmer, February, 1970.
8. Contributed by Piyush Swami, Research Associate, Science Youth Project, Regional College of Education, Ajmer.

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SUBJECT INDEX

Bending of a seedling 78-79

Electron
    concept 77
    emergence 113-27

Foods 97-99

History of science cases 142-44
Hypotheses, formulating and testing 68-69

Inventive wizard 131-36
Investigative projects
    features 17-19
    focus 14-16
    functions 16-17
Investigative questions 226-35
    and long essays 236-38
Investigative science 1-19
Investigatory projects in zoology 149-53

Jungle to zoo 95-97

Life, the origin of 106-13

Measuring the velocity of light 136-42
Minerals 104-106
Mysterious nervous disease 79-80

Point investigations and improvisations 238-49
Project ideas in
    biology 263-69
    chemistry 258-63
    other interesting projects 270
    physics 250-57
Projects
    evaluation 172-73
    preparing and judging 289-93
    procedure for studying 173-74

Science :
    definitions and their appraisal 4-5, 33-43, 45
    limitations 45-47
Science and technology : impact 22-27
Science as past adventure 72-145
Science Club 282-87
Science education :
    assumptions 31-33
    functions 29-31
    objectives 48-50
    role 27-29
Science exhibition 287-89
Science Youth Project 278-82
Scientific enterprise : nature 21-54
Scientific methods 3, 69-70
    steps in scientific method 70-71
    stress on productive thinking 276-78

Thinking 62-64
    logical steps in problem-solving 67-68
    problem-solving and 65-67
    productive 64-65

Universe and the shape of the earth 80-94

Vitamins, the story of 99-104

AUTHOR INDEX

Aepinus 118
Alhazen I37
Allan, A. Van 271
Ampere 113, 119, 143
Anderson 125
Andrade, E.N. da C. 21
Appleton 9
Aquinas, Thomas 107
Archimedes 92
Aristotle 58, 91, 93, 107, 137, 138
Armstrong, Garner 24
Armstrong, Herbert 24
Arrhenius 110
Ashby, Eric 1, 15, 46, 78
Asimov, Isaac 105
Augustine, St. 113, 114
Austin 68

Bacon, Francis 59, 60
Bacon, Roger 59
Baird, John Logie 7
Balfour 9
Bartlett 63
Baumel, Howard B. 52
Berger, J. Joel 52
Beddoes, Thomas 127-28
Bancroft 36
Bernard, Claude 36
Berzelius 9, 10, 96
Bernal, J.D. 35, 40, 140, 297
Biot 119
Blake, William 51
Bonnet, Charles 108
Bose, G.B. 117
Brownski, Jacob 36
Boyle, Robert 10, 70, 115, 137
Bridgman, Percy 2, 43
Boysen-Jensen 78
Bruno, Giordono 59, 94
Burt 63, 67
Burrack 67

Cabeo, Niccolo 113, 115
Cardan, Jerome 113, 114
Cavendish 80
Cohen 124
Cohen, R. Sonne 29, 295
Columbus 4, 77, 108, 113, 118
Conant, J.B. 36, 38, 109, 143
Copernicus 70, 92, 93, 94, 95
Crookes, William 119, 120
Curie, M. 222

Daguerre, Mande 7
Daley, Michael J. 46
Dalton, John 130
Darwin, Charles 62, 78, 79, 87, 110
Davy, Humphry 127, 130, 131, 143
Dean 67
Debye, Peter J.W. 82
Descartes, Rene 61, 137
Dewey 67
Diederich, Paul B. 49
Dirac, P.A.M. 125
Dufay 113, 117, 118
Dumas 109
Duncker 68

Edison 86, 135
Eijkman, Christian 102, 103, 104
Einstein 39, 43, 52, 60, 61, 70, 95, 140, 142

Faraday, Michael 9, 113, 119, 121, 123, 131, 143
Feynan, P. 271
Fitzgerald, G.F. 140
Fitzpatrick, F. 38
Fizeau, A.H. 137, 139
Flesch, Rudolph 297
Frank, P. 36
Foucault, Jean 137
Franklin, Benjamin 117

Galavani 113, 118
Galelio 17, 59, 60, 69, 94, 137
Gall 60
Geber 10
Gilbert, Archey 34
Gilbert, William 113, 114, 115
Glass, Bentley 2, 88
Godfrey 116
Goldstein 119, 120, 122, 123
Goodnow 68
Grahm, George 9
Grassi, Giovanni B. 86
Gray, J. Stanley 66, 67
Gray, Stephen 116
Griggs, Cedric 42
Guru, G. 149

Haldane, J.B.S. 111
Hanson, N.R. 77
Harvey, William 60, 107
Hauksbee, Francis 115, 116, 117
Hearnshaw 63
Helmont, J.V. 4, 107
Hertz 119, 120, 121
Hillebrand, W.F. 81, 82
Hippocrates 83
Hook, Robert 137
Humphrey 63, 67
Hurd, Paul D. 23
Huxley, Aldous 75
Huxley, J.H. 75
Huygens, Christian 138

James, William 4
Jackson 12, 13
Jacobson, W.J. 40
Joshi, A.C. 296

Kant, Immanuel 27
Kelvin, 9, 123
Kepler, John 60, 70, 94, 137, 143
Khruschev 50
Knight, David D. 95
Kogol 79

Laveran 84
Lavoisier 10, 52, 60
Leeuwenhoek 72, 108
Leibnis 72
Lenard, Philip 121, 122
Lodge, Oliver 122, 139, 140
Lewis 126
Lind 100, 101, 102
Lorentz, H.A. 121
Luther, Martin 93

Maier 65
Manson, Patrick 84, 85, 86
Marcuse, Herbert 31
Maxwell 120, 138
Mendeleev, Dimitri 41, 96, 97
Michelson, A.A. 138, 139, 140, 141
Mill, J.S. 61
Millikan, R.A. 124
Mills 67
Morgan, Thomas Hunt 271

Needham 108
Newton 10, 51, 60, 70, 94, 96, 107 113, 139
Nicephore, Niepce 6, 7

Oakeshett, Michael 56
Oersted 113, 119, 143
Ohm, F.G. 113
Ohm, G.R. 119
Oprian, A.I. 111
Oppenheimer, Robert 24, 36

Parsons, C.A. 38
Pasteur, L. 4, 73, 102, 109, 220
Pauli, W. 3, 41
Pavlov 222
Pearson, Karl 22, 41, 70
Peel, E.A. 63
Perkins 51
Piaget 64, 65
Planck, Max 123, 140
Plato 58, 113, 297

Polya 67
Priestley 118
Pouchet 109
Prout, William 97
Ptolemy, Clauduis 70, 92, 93, 137
Pultarch 113, 114, 115

Raleigh, Lord 80
Ramsay, William 80, 81
Randall 126
Reaumer, Renes 98
Redi, F. 108
Ringer, Sidney 105
Rontgen, W.K. 122
Rose, William C. 99
Ross, Ronald 82
Rumford 129
Russell, B. 59, 63

Sanctorius, Santorio 97
Scheele, K.W. 130
Schrodinger 77
Snow, C.P. 3
Socrates 58
Spallanzani, Lazarro 98, 108, 109
Spencer, Herbert 272
Stephenson, George 130
Suchman, J.R. 276

Takaki 101, 102, 103
Thales 90, 91
Thomson, George 70
Thomson, G.P. 125
Thomson, J.J. 70, 77, 121, 123, 140
Toulmin, Stephen 278, 297
Townes, C.H. 141
Tyndall, John 2, 56

Urey, Harold 19

Vaidya, N. 2, 37
Vinci, Leonardo da 6, 92
Volta 113, 143

Wald, George 111
Weaver, Warren 37
Weiss, Paul 38
Welch 65
Went 79
Wertheimer, Max 64
Westinghouse 131
Wheeler 51
Wilson, H.A. 123
Woehler, Friedrick 9, 10, 98

Zacharias 51
Zeeman, Pieter 121

HOW CHILDREN DISCOVER KNOWLEDGE

NARENDERA VAIDYA

Unlike countries, science has 'open frontiers'. In this century, it has come of age: endless and faceless, stable and fluid, its inside exploding and imploding at the same time. At home, it lacks hypotheses setting and testing philosophy for it is still approached dogmatically in its entirety: teaching, telling, learning, experimenting and examining. *How Children Discover Knowledge*, therefore, attempts to illuminate the very reflective bases of science by encouraging youngsters to innovate, master stimuli rather than restraints, while trying hard to reach destination with or without direction—for major scientific advances take place only when either the fairly well established body of scientific knowledge is challenged imaginatively or the most funniest scientific ideas are entertained, woven or left over partially by joining part fragments to each other like fibres in a long rope.

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